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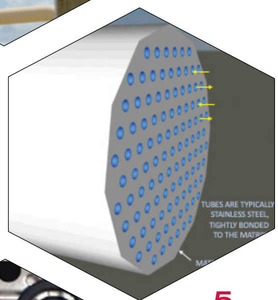

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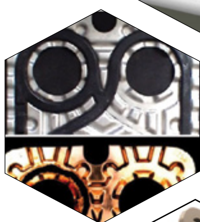

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Cover design: Tara Bekman

Cover photo: courtesy of Smith & Burgess Process Safety

Editor's Page

The 'Green' Chemistry Challenge

The Green Chemistry Challenge Awards recognize scientific solutions to environmental problems that reduce hazards associated with the design, manufacture and use of chemicals. The U.S. Environmental Protection Agency (EPA) Office of Chemical Safety and Pollution Prevention sponsors the awards in partnership with the American Chemical Society (ACS) and other members of the chemical community. This year, a new award category for climate change was added to recognize technologies that reduce or eliminate greenhouse gas emissions. A brief summary of the 2022 winners follows [*1*]:

***Greener Synthetic Pathways* — Merck & Co., Inc.** (www.merck.com) has once again received this award for its achievement in creating a "greener" process. Merck developed a process for manufacturing molnupiravir (tradename LAGEVRIO), an antiviral medication for treating COVID-19, with less organic solvent waste and less energy use. Breakthroughs in the process development include a dynamic crystallization with product selectively crystallizing as it is formed; direct isolation by changing the solvents used, which decreased byproduct formation and increased purity; and utilization of a novel multi-enzyme cascade to increase the efficiency of the process.

***Greener Reaction Conditions* — Amgen** (www.amgen.com) was awarded this honor for an improved manufacturing process for sotorasib (tradename LUMAKRAS), which is a drug for treating certain non-small-cell lung cancers. Amgen decreased the number of reaction steps in the commercial manufacturing process by using telescoped synthesis. This involves creating sequential reactions in one vessel by adding reagents one at a time, thereby eliminating intermediate separation and purification steps. Additional changes, including a recycling step, were also implemented to achieve a more sustainable process.

***Small Business* — Provivi** (www.provivi.com) was recognized for its green solution for crop protection against pests. Provivi's product, tradenamed ProviviFAW, is a pheromone produced from renewable plant oils. It targets the fall armyworm moth that is destructive to corn and other crops. The company improved the reaction to make this type of pheromone by using fermentation to produce raw materials from plants instead of petroleum. In addition to creating a more sustainable synthesis route, use of the pheromone in place of traditional pesticides offers ecological benefits.

***Academic* — Professor Song Lin** of Cornell University's Dept. of Chemistry and Chemical Biology (www.cornell.edu) received this award for developing a new route to manufacture complicated molecules that are typically needed in pharmaceuticals. The technology employs an electrochemical approach that uses inexpensive carbon or magnesium electrodes and eliminates the need for transition metal catalysts.

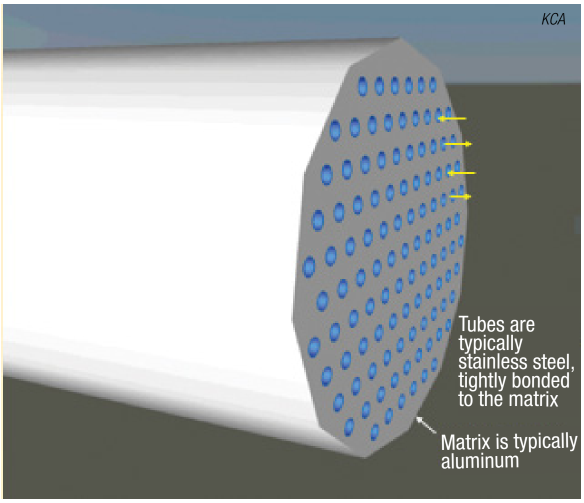
***Specific Environmental Benefit, Climate Change* — Professor Mark Mascal** at the University of California at Davis (www.ucdavis.edu) in partnership with Origin Materials (www.originmaterials.com) was recognized for developing a process using acidic digestion of biomass to make 5-(chloromethyl)furfural (CMF). CMF is a bio-based platform chemical that can be used to replace petroleum-based feedstocks to manufacture a variety of chemicals. Origin Materials has developed a process for polyethylene terephthalate (PET) from CMF. ■

Dorothy Lozowski, Editorial Director

1. Source: EPA; more details about the winners and the awards can be found on the EPA's website, www.epa.gov

Edited by:
Gerald Ondrey

New design allows countercurrent heat exchange with hard-to-process slurries



Countercurrent heat-exchange with difficult slurries, such as those of mineral ore or stringy vegetables, has not been possible because suspended solids pack and foul the shell of shell-and-tube designs and plug the passages in plate-and-frame units.

Now, a recently patented heat-exchanger design in which a solid matrix of conductive material surrounds two sets of alternating, adjacent tubes makes it possible to effectively transfer heat between two slurries. Developed by the mining engineering firm Kappes, Cassiday & Associates (KCA; Reno, Nev.; www.kcareno.com), the exchanger has the potential to substantially reduce energy and maintenance costs, says the company.

The new design has a similar appearance to a conventional shell-and-tube heat exchanger, but the hollow shell is replaced by a solid heat-exchange matrix of aluminum (diagram). One slurry to be heated or cooled is flowed in one direction through the heat exchange section using one set of stainless-steel tubes, while another fluid is flowed through a second set of parallel tubes in the opposite direction.

The spacing of the tubes is based on mathematical modeling of heat flow between the two intercalated sets of tubes, and is set so that heat flows perpendicularly between adjacent tubes. According to KCA, the tube spacing must be close to maximize perpendicular heat flow, but not too close, which would make construction very expensive.

The patented technology includes a system for coupling the tubes to link modules together to lengthen the heat-exchange range. KCA points out that while the exchanger was designed for mineral slurries, many variations on the concept are possible for other applications.

Polymer-coal composite used for building materials

X-Materials (Orlando, Fla.; www.x-materials.com), the advanced materials division of Semplastics Inc., has developed a method for manufacturing a coal-containing ceramic polymer-composite material that is being used to make building materials, such as roofing tiles, as well as other products.

According to X-Materials founder Bill Easter, the material, known as Coal Core Composite (CCC), combines desirable properties from three material types: the high strength and durability of metals; the high-temperature and fire resistance of ceramics; and the lightweight of plastics, while also sequestering coal carbon. The CCC is formed by heating powdered coal with a proprietary resin to form a chemically bound (rather than sintered) silicon-oxygen-carbon composite, Easter says.

"There's been a great deal of interest in these types of materials in the past, but producing them cost-effectively at scale has been elusive," Easter explains. "We've been able to solve those issues with the CCC."

X-materials recently received a research and development contract from the U.S. Department of Energy's National Energy Technology Laboratory (Morgantown, W.Va.; netl.doe.gov) to build a prototype dwelling made mostly from coal-derived building materials, including roof tiles, siding panels, bricks and blocks. The company previously established a manufacturing line in Bluefield, W.Va. for the production of the roofing tiles. X-Materials plans to have the house constructed by 2023.

In parallel to the production of CCC for building materials, another team within the company is developing coal-containing composites for high-capacity battery anodes for lithium-ion batteries. Other applications under development for the composites include high-temperature plastics, 3D printing and spacecraft and satellite components.

CELLULOSIC ETHANOL

Clariant AG (Muttenz, Switzerland; www.clariant.com) has produced the first commercial cellulosic ethanol at its sunliquid production plant in Podari, Romania. The entire offtake is contracted with a multi-year agreement to Shell. Over the last six months, the plant — the first commercial unit to apply sunliquid technology — underwent a thorough commissioning process, resulting in the successful start of production. Approximately 50,000 tons of second-generation biofuels will be derived from 250,000 tons of locally sourced agricultural residues. The cellulosic ethanol produced at this plant can be applied as a drop-in solution for fuel blending, but also offers further downstream application opportunities for sustainable aviation fuel and bio-based chemicals.

"The advanced biofuel produced by the sunliquid technology process supports the decarbonization of the transport sector by providing up to 120% CO_2 savings compared to fossil fuel," says Christian Librera, head of Business Line Biofuels & Derivatives.

Sunliquid is a biotechnological method for manufacturing cellulosic ethanol from agricultural residues, such as cereal straw, corn stover or sugar-cane bagasse. In the completely integrated process, highly optimized, raw material-specific biocatalysts decompose cellulose and hemicellulose in high yields under stable processing conditions into fermentable sugar. The process-integrated production of the biocatalysts offers flexibility and reduces production costs. In the next step, an optimized fermentation organism simultaneously converts C5 and C6 into ethanol with high yields and short reaction times. A highly optimized purification process is instrumental in enabling all the en-

(Continues on p. 6)

ergy required for the process to be derived from the process byproducts, such as insoluble lignin.

DELIGNIFICATION

Researchers from Washington State University (Pullman; www.wsu.edu) and the U.S. Dept. of Energy's Pacific Northwest National Laboratory (PNNL; Richland, Wash.; www.pnnl.gov) have developed an artificial enzyme that digests lignin, which has stubbornly resisted previous attempts to develop it into an economically useful energy source. "This is the first nature-mimetic enzyme that we know can efficiently digest lignin to produce compounds that can be used as biofuels and for chemical production," according to Chun-Long Chen, a corresponding author, a PNNL researcher and affiliate professor in chemical engineering and chemistry at the University of Washington.

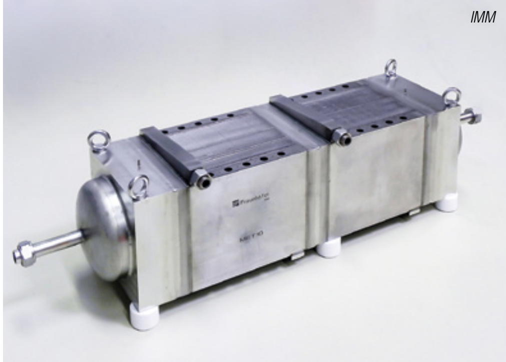
Enzymes offer a much more environmentally benign process than chemical degradation, which requires high heat and consumes more energy than it produces. In nature, fungi and bacteria are able to break down lignin with their enzymes, but natural enzymes degrade over time, which makes them hard to use in an industrial process. They're expensive, too.

In the current study, the researchers replaced the peptides that surround the active site of natural enzymes with protein-like molecules called peptoids. These peptoids then self-assembled into nanoscale crystalline tubes and sheets that have a high density of active sites. "We can precisely organize these active sites and tune their local environments for catalytic activity," says Chen. The new enzymes can also work at higher

(Continues on p. 7)

Boosting methane yields in biogas plants

Biogas plants play an important role in defossilization — anaerobic bacteria in these plants break down biomass to form biogas which, on average, comprises up to 60% methane and more than 40% CO_2. While the biogas is used to generate electricity and heat in combined power-and-heating (CPH) units or can be upgraded to natural gas quality and fed into the natural gas network, the CO_2 has not been utilized to date. Instead, it is typically released to the atmosphere. Now, as part of the ICOCAD projects, researchers from the Fraunhofer Institute for Microengineering and Microsystems (IMM, Mainz, Germany; www.imm.fraunhofer.de) are developing a way to convert CO_2 into additional methane.



The underlying chemical reaction — the Sabatier process; $CO_2 + 4H_2 \rightarrow CH_4 + 2H_2O$ — was discovered more than a hundred years ago, but to date it has not been used for direct upgrading of biogas. This endothermic reaction requires a high temperature (around 400°C), which not only reduces the maximum CO_2 conversion through thermodynamic equilibrium, but also favors the undesired competing reverse water-gas shift reaction. Also, sulfur compounds generated in the biogas plant can poison the catalyst.

The goal of the ICOCAD I project was to improve the catalyst stability against small amounts (below 1 part per million (ppm)) of sulfur remaining after the sulfur-removal trap, as well as reducing other deactivation processes, such as coking and sintering. Nickel and ruthenium-based catalysts were studied, both in fixed-bed and microchannel reactors (photo). The selected catalyst achieved constant CO_2 conversion and CH_4 selectivity in long-term (1,000 h) durability tests. When exposed to H_2S in the feed, the nickel-containing-catalyst formulation showed improved stability, as it served as a sulfur trap.

The plant concept consists of a two-step methanation with a first adiabatic reactor stage, followed by a plate heat-exchanged reactor with integrated cooling. Such a system achieved more than 97% CO_2 conversion. In the ICOCAD I project, a pilot plant was built that converts 1 m^3/h of biogas into 1 m^3/h of CH_4, using a 10-kW electrolyzer to supply the H_2. In a follow-up project, ICOCAD II, the researchers are scaling this up by a factor of five, and plan to have this operating by 2023. Scaleup to 500-kW is envisioned by 2025, and to 2-MW by 2026.

A 'liquid' platinum catalyst outperforms solids at low temperature

Platinum is widely used for many catalytic reactions, and because the precious metal is so expensive, efforts have been ongoing to reduce the amount of Pt required to perform reactions. Among these efforts are the use of nano-dispersions, clusters and even single atoms on different supports. Now, researchers from the University of New South Wales (UNSW; Sydney, Australia; www.unsw.edu.au), in collaboration with scientists from the Royal Melbourne Institute of Technology (RMIT; Australia), Deakin University (Victoria, Australia) and the University of California at Los Angeles, have demonstrated, for the first time, a new way to support platinum catalysts that significantly reduces the amount of Pt required to catalyze reactions — even at low temperature.

The concept — described in a June issue of *Nature Chemistry* — is to dissolve traces of liquid Pt into a solvent-like gallium matrix. Because Ga melts at around 30°C, this liquid-supported Pt catalyst can be used at low temperatures. The Pt atoms in the Pt-Ga system were shown to remain atomically dispersed without segregation, as well as being free to move through the liquid via diffusion. This dynamic property of the Pt in Ga was demonstrated, both by simulations and by experiments in which deactivation was found to be negligible. Alternative support systems that fix the Pt in place make the active sites prone to deactivation once the reaction is running.

To make the catalyst system, Pt beads are dissolved in molten Ga at around 400°C, then cooled to the operating temperature of the reaction (typically 40–80°C). In one (of several) reaction studied, the electrochemical oxidation of methanol using the Pt-Ga system as the anode was shown to have an activity of around 2.8×10^7 milliamp per milligram of platinum, which is three orders of magnitude higher than existing solid platinum catalysts.

Upcycling aerospace scrap materials into new membranes

A new membrane for separating emulsions is being fabricated using recycled carbon-fiber production scraps from aerospace manufacturing. "We think this is the first membrane of its type to be constructed from recycled carbon fibers," explains Shuaifei Zhao, senior research fellow in the Institute for Frontier Materials (IFM) at Deakin University (Victoria, Australia; www.deakin.edu.au), where the new membrane was developed.

In order to prepare the scrap carbon fibers for use in the membranes, the IFM team applied a specialized recycling process involving pyrolysis, thermal oxidation and ball milling. "Typically, the spent composite was heated in a nitrogen atmosphere at high temperatures to degrade the polymer resin, forming a char on the fibers. Then, the material is heated again in air, which provides an oxidizing atmosphere to completely degrade any residual char and oxidize residual char from the fiber surface," says Zhao. Once these treatment steps are complete, the reclaimed fibers undergo ball milling and sieving to obtain the desired fiber length.

To fabricate the membrane, a dip-coating method was used wherein the substrate membrane was dipped into a dispersion of functionalized carbon fibers in tannic acid (a common crosslinking substance), in the presence of a 3-aminopropyl triethoxysilane (APTES) solution. "The key novelty is the functionalization of the reclaimed carbon fibers to construct a special hierarchical structure, which increases the membrane's surface roughness and improves the reaction between the fibers, tannic acid and APTES, providing the membrane with its superhydrophilic and underwater superoleophobic properties," adds Zhao.

The carbon-fiber-recycling process has been scaled up for industrial production by Gen2 Carbon Ltd. (West Midlands, U.K.; www.gen2carbon.com). IFM is working to demonstrate the membrane's performance in industrial conditions, focusing on long-term stability, cleaning requirements and replacement frequency. The team expects that the membrane could have wide-ranging applications with favorable economics, since the use of recycled materials lowers overall membrane-construction costs and the fabrication process can be readily automated.

temperatures (60°C) that natural ones.

H_2O_2

Scientists from Tokyo University of Science (www.tus.ac.jp) and Nara Women's University (both Japan; www.nara-uu.ac.jp) have demonstrated a way to make hydrogen peroxide from spent coffee grounds (SCG) and tea leaf residue (TLR). Both SCG and TLR are generated in large quantities as a waste product from coffee and tea, which are the two most popular beverages in the world. Both waste products also contain polyphenols, which can easily, and cost-effectively produce H_2O_2.

The team's production method involved

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adding coffee grounds and tea leaves to a sodium phosphate buffer, then incubating this solution while shaking it. In the presence of the buffer, SCG and TLR interacted with O_2 to produce H_2O_2. This method is much simpler and more environmentally friendly than the conventional anthraquinone process.

The study — published last month in *ACS Omega* — also details the use of this H_2O_2 produced from biomass to synthesize other chemicals, for example, the H_2O_2-promoted enzymatic oxidations of 4-methoxy-1-naphthol to Russig's blue (a model reaction to test the peroxygenation activity of enzymes), and the enzymatic oxidation of styrene to styrene oxide and phenylacetaldehyde.

RECYCLING TEXTILES

Worn Again Technologies (Nottingham, U.K.; www.wornagain.co.uk) is in the final planning stages of a demonstration plant that will showcase its ground-breaking polymer processing technologies for textile recycling. The facility, which will be built and operated by the company, is to be constructed in Winterthur, Switzerland and will have the capacity to recycle 1,000 m.t./yr of textiles.

The new industrial-scale infrastructure will help validate the closed-loop chemical recycling solution that has been developed by Worn Again Technologies and its strategic partners, including Sulzer Chemtech Ltd. (Winterthur, Switzerland; www.sulzer.com). The process obtains polyethylene terephthalate (PET) and cellulose from non-reusable, hard-to-recycle textiles that constitute post-industrial and post-consumer waste. Additionally, the process purifies the products by removing dyes, contaminants and impurities, a step forward from traditional recycling methods, the company says.

Last month, Worn Again Technologies launched the Swiss Textile Recycling Ecosystem, an initiative that brings together key industry players across the entire textile value chain.

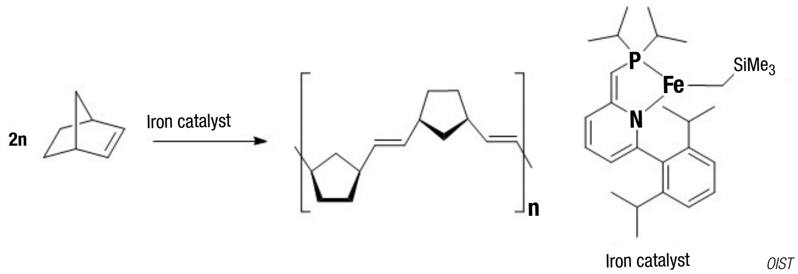
(Continues on p. 9)

Iron catalyst shows promise for improving economics of metathesis reactions

The olefin metathesis reaction produces new carbon-carbon double bonds by swapping the carbon atoms in olefins, and is important for producing a number of chemicals. Currently, the most popular catalysts for this reaction are made from the precious metal ruthenium or molybdenum. Now, researchers from Okinawa Institute of Science and Technology Graduate University (OIST; Japan; www.oist.jp) have designed an iron-based catalyst as an economical alternative to conventional Ru-based catalysts. Described in a June issue of *Nature Catalysis*, the new catalyst is a three-coordinate iron(II) catalyst (diagram, right), which was demonstrated to perform ring-opening metathesis polymerization of olefins.

For example, OIST's catalyst was shown to enable the formation of polynorbornene (diagram) with stereoregularity and high molecular weight (greater than 10^7 g/mol). The polymerization of norbornene in the presence of styrene revealed cross-metathesis reactivity with the iron catalysts. A mechanism was also developed to describe the reaction.

Despite the success of this research, OIST researcher Satoshi Takebayashi, and lead author of the study, cautions that more work is required, and that today's state-of-the-art Ru-based catalysts are still much more applicable than the newly created iron-based ones. For example, the iron catalyst is unstable and less active when exposed to air and moisture. These limitations need to be addressed before the iron-based catalyst can replace the Ru one, he says.



OIST

Recycling Portland cement — emissions-free

The production of clinker used for making cement continues to be a major source of global CO_2 emissions. Now, three engineers from the University of Cambridge (U.K.; eng.cam.ac.uk) have filed a patent and been awarded new research funding for their invention of what is said to be the world's first emissions-free route to recycle Portland cement.

The inspiration for the so-called Cambridge Electric Cement struck inventor Cyrille Dunant when he noticed that the chemistry of used cement is virtually identical to that of the lime-flux that is already being used in conventional steel-recycling processes that use electric-arc furnaces (EAF). The new cement is therefore made in a virtuous recycling loop, which not only eliminates the emissions of cement production, but also saves raw materials, and even reduces the emissions required in making lime-flux.

The new process begins with concrete waste from the demolition of old buildings. This is crushed, to separate the stones and sand that form concrete from the mixture of cement powder and water that bind them together. The old cement powder is then used instead of lime-flux in steel recycling. As the steel melts, the flux forms a slag that floats on the liquid steel, to protect it from oxygen in the air. After the recycled steel is tapped off, the liquid slag is cooled rapidly in air, and ground up into a powder that is virtually identical to the clinker which is the basis of new Portland cement.

In pilot-scale trials of the new process, the Cambridge team have demonstrated this combined recycling process, and the results show that it has the chemical composition of a clinker made with today's process.

The new cement was invented as part of the large multi-university UK FIRES program, led by professor Julian Allwood, which aims to enable a rapid transition to zero emissions based on using today's technologies differently, rather than waiting for the new energy technologies of hydrogen and carbon storage. Invention of the cement has been rewarded with a new research grant of £1.7 million ($2.1 million) from the Engineering and Physical Sciences Research Council (EPSRC; Swindon, U.K.) for further development.

‘Symbiotic’ electrolyzer runs on waste heat

A new steam-fed electrolyzer aims to bridge the gap between liquid-water electrolyzers, many of which require exotic materials and intricate membranes, and solid-oxide electrolyzers, which require superheated steam and temperatures as high as 800°C. This ‘symbiotic’ electrolyzer, developed by Advanced Ionics (Milwaukee, Wis.; www.advanced-ionics.com), is designed for operation at intermediate temperatures, so it can utilize onsite process and waste heat at temperatures of 100°C and up. “We don’t think there has been another electrolyzer specifically developed to operate at typical industrial heat temperatures, which enables close synergy with industrial processes that use H_2,” says Chad Mason, CEO and founder of Advanced Ionics. The ability to operate with steam and tap into existing process heat can reduce the electricity expenditure to as low as 30–35 kWh per kg of H_2, whereas other electrolyzer configurations typically require 40–50 kWh/kg. The efficiency gains from using existing process heat means that the electrolyzers are suitable for installation both within existing plants and for greenfield construction. “We know there are sites that do not want to wholesale switch out their steam methane reformer, but they might need to add 10 to 20% green H_2 to capture some incentives, or mitigate carbon taxes. We can provide those marginal capacity additions to append onto an existing installation,” says Mason.

“And in a greenfield ammonia plant, for instance, the Advanced Ionics electrolyzers could take that the steam off of the Haber-Bosch reactor and from some of the other heat-generating locations at the site. We’re designing the units to work with many thermal-transfer mediums,” he adds.

Advanced Ionics’ electrolyzer is constructed mainly of commodity materials, such as stainless steel. “We don’t use any platinum-group metals or perfluorinated membranes, so from a cost and supply chain perspective, as well as recyclability, it’s a very friendly architecture,” explains Mason. And unlike other electrolyzers, no deionized water is required — the steam feed just undergoes reverse osmosis. Thus far, the electrolyzer has been operated at the laboratory scale, but a scaleup endeavor is underway, with the expectation that gigawatt-scale capacity could be achievable in five years. ■

H_2 GAS TURBINE

Researchers at the University of Stavanger (UiS; Norway; www.uis.no) operate a micro gas plant in south-west Norway. The gas turbine produces both heat and electricity, and supplies water for heating the laboratory buildings in the immediate area. In addition, surplus energy is supplied to power provider Lyse’s district heating and electricity grids.

The researchers have been developing a method for using pure H_2 as fuel in the gas turbine. In mid-May 2022, an important milestone was reached — the researchers started running the turbine on 100% H_2. The micro gas-turbine plant is a collaboration with the German Aerospace Center (Cologne; www.dlr.de), which provided the combustion chamber. ❐

Business News

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Plant Watch

Solvay completes PVDF capacity expansion in Changshu

June 13, 2022 — Solvay S.A. (Brussels, Belgium; www.solvay.com) has significantly increased production capacity for polyvinylidene fluoride (PVDF) at the company's site in Changshu, China. Solvay has now more than doubled the onsite production volume of high-performance PVDF since mid-May 2022.

Evonik Care Solutions expands manufacturing plant in Shanghai

June 9, 2022 — Evonik Industries AG (Essen, Germany; www.evonik.com) has expanded its manufacturing capacity for myristyl myristate (MM) at its Care Solutions organics plant in Shanghai, China. The expanded plant employs an enzymatic process esterification based on 100% renewable energy. Evonik also produces MM at a site in Duisburg, Germany.

Air Products awarded hydrogen and nitrogen supply agreement for IOCL

June 9, 2022 — Air Products (Lehigh Valley, Pa.; www.airproducts.com) will build, own and operate a new industrial gases complex supplying hydrogen, nitrogen and steam to Indian Oil Corp.'s (IOCL; New Delhi; www.iocl.com) Barauni Refinery in Bihar, India. The new complex will include a hydrogen production facility supplying 70,000 m^3/h of hydrogen, as well as steam, and a high-efficiency air separation unit producing 4,000 m^3/h of nitrogen. Air Products expects the new industrial gas complex for IOCL to come onstream in 2024.

Chevron Phillips to construct new polyalphaolefins unit in Belgium

June 7, 2022 — Chevron Phillips Chemical (The Woodlands, Tex.; www.cpchem.com) announced plans to expand its polyalphaolefins (PAO) business with the construction of a new unit in Beringen, Belgium. Once local permits are approved, this investment will double the company's PAO production capacity in Belgium to 120,000 metric tons per year (m.t./yr) upon targeted startup in 2024.

Repsol to build new plant for ultra-high-molecular-weight polyethylene

June 6, 2022 — Repsol S.A. (Madrid, Spain; www.repsol.com) will invest €105 million in its Puertollano Industrial Complex in Spain to build a new manufacturing plant for ultra-high molecular weight polyethylene (UHMWPE). This new plant will start up by the end of 2024 and will have a capacity of 15,000 m.t./yr. For the construction of the plant, Repsol has selected technology from Royal DSM N.V. (Herleen, the Netherlands; www.dsm.com).

Evonik to build new lipids production facility in Indiana

Evonik is building a new world-scale production facility for pharmaceutical lipids at the company's Tippecanoe site in Lafayette, Ind. Construction will begin in early 2023, and the plant is scheduled to go onstream in 2025. The total investment amounts to $220 million.

Nippon Shokubai and Arkema to launch joint production of electrolyte salts

May 31, 2022 — Nippon Shokubai Co. (Osaka, Japan; www.shokubai.co.jp) and Arkema S.A. (Colombes, France; www.arkema.com) are joining forces to launch feasibility studies and establish a joint venture (JV) for the construction of an industrial plant for the production of lithium bis(fluorosulfonyl)imide (LiFSI) ultrapure electrolyte salts, a key component of battery cells for electric mobility. The JV envisions mass production of LiFSI electrolyte salts at Arkema's Pierre-Bénite site in France by the end of 2025.

Wacker to expand silicon-metal plant in Norway

May 26, 2022 — Wacker Chemie AG (Munich, Germany; www.wacker.com) intends to expand its production capacity for silicon metal at Holla, Norway. The construction of a new furnace is planned, which will increase capacity in Holla by around 50% of its current level.

Orion Engineered Carbons to expand gas black capacities in Germany

May 26, 2022 — Orion Engineered Carbons (Houston; www.orioncarbons.com) is planning to complete its gas black expansion in Germany at plants in Dortmund and Cologne by early 2023. Gas blacks are used in coatings, printing ink and other applications.

Air Liquide inaugurates $250-million hydrogen plant in Nevada

May 24, 2022 — Air Liquide S.A. (Paris, France; www.airliquide.com) opened its largest liquid hydrogen production and logistics infrastructure facility in North Las Vegas, Nev. The facility, and the associated logistics infrastructure, marks a $250-million investment by Air Liquide. The facility will produce 30 ton/d of liquid hydrogen.

Merck to expand membrane and filter manufacturing capacity in Ireland

May 24, 2022 —Merck KGaA (Darmstadt, Germany; www.merck.com) is expanding its membrane and filtration manufacturing capabilities in Ireland. The company will invest around €440 million to increase membrane manufacturing capacity in Carrigtwohill and to build a new manufacturing facility at Blarney Business Park, both in Cork, Ireland.

Mergers & Acquisitions

Borealis receives binding offer for sale of its nitrogen business

June 6, 2022 — Borealis Group (Vienna, Austria; www.borealisgroup.com) has received a binding offer from Agrofert, a.s. (Prague, Czech Republic) for the acquisition of Borealis' nitrogen business, including fertilizer, melamine and technical nitrogen products. The offer proposes an enterprise value of €810 million. Closing is expected in the second half of 2022.

DuPont completes sale of Biomaterials business unit

June 2, 2022 — DuPont (Wilmington, Del.; www.dupont.com) completed the sale of its Biomaterials business unit to the Huafon Group (Ruian, China) for approximately $240 million. Huafon Group specializes in polyurethane materials, including adipic acid, polyester polyols, microfibers, polyamide and more.

Lanxess and Advent to acquire DSM Engineering Materials

May 31, 2022 — Lanxess AG (Cologne, Germany; www.lanxess.com) and Advent International (Boston, Mass.) are establishing a JV for high-performance engineering polymers. The two companies signed an agreement to acquire DSM Engineering Materials (DEM) for around €3.7 billion. DEM will become part of the new JV, along with Lanxess' High Performance Materials business unit. DEM produces polyamides, as well as various specialty materials.

LG Chem and B&M to establish JV to produce cathode material

May 30, 2022 — LG Chem Ltd. (Seoul, South Korea; www.lgchem.com) announced the formation of a JV with Tianjin B&M Science and Technology (B&M), a subsidiary of China's Zhejiang Huayou Cobalt (Huayou Cobalt) that specializes in cathode materials. Both partners have committed KRW500 billion (approximately $403 million) toward the initiative by 2025.

Johnson Matthey divests Battery Materials business assets

May 27, 2022 — Johnson Matthey plc (JM; London; www.matthey.com) has entered into an agreement for the sale of part of its Battery Materials business to EV Metals Group (Perth, Australia). The sale to EV includes JM assets in Oxford, U.K. and a pilot plant in Billingham, U.K., as well as a research center in Moosburg, Germany and the partly constructed site in Konin, Poland. The sale does not include Johnson Matthey's battery materials business in Canada, which will be acquired by Nano One Corp. (Vancouver, B.C., Canada) for around $8 million. The assets acquired by Nano One include a 2,400-m.t./yr production facility in Candiac, Québec that supplies lithium-iron-phosphate (LFP) cathode material.

Saint-Gobain sells glass businesses in Austria and Germany

May 27, 2022 — Saint-Gobain S.A. (Courbevoie, France; www.saint-gobain.com) announced the sale of its glass-processing businesses Eckelt Glas and Glas Ziegler in Austria to the German firm Aequita, as well as the sale of its holding in the co-venture Glaskontor Erfurt — a glass-processing business in Germany — to the Caleoglas Group. The businesses generated sales of around €55 million in 2021. ■

Mary Page Bailey

Traversing a Data-Powered Supply Chain

Transporting chemical products across global supply chains is complex and challenging, but data-supported technologies are helping to improve efficiency, sustainability and reliability

Materials produced by the chemical process industries (CPI) are used in nearly all global product chains. According to the Science Based Targets Initiative, around 95% of manufactured products rely on chemical goods. This ubiquity serves to amplify the supply-chain disruptions brought about by labor shortages and the persistent economic effects of the pandemic. A study conducted in late 2021 by the American Chemistry Council (ACC) surveyed 67 chemical manufacturers, who overwhelmingly reported that supply-chain problems were creating lost production (66% of respondents), shipping delays (94% of respondents) and increased transport costs (93% of respondents). Furthermore, the ACC study indicated that the materials shortages and cost increases caused by production and shipping disruptions were impacting 85% of those surveyed.

This increased focus on supply-chain issues coincides with the CPI's continued efforts to improve the environmental sustainability of their products and processes, and also the industry's continued foray into digitalization. This article looks at the supply-chain trends that are affecting the CPI and the new technologies that are aiming to streamline supply and logistics operations.

FIGURE 1. Because hazardous materials require special shipping considerations when compared to non-regulated materials, access to pertinent data is crucial at all nodes of the supply chain to ensure safe and compliant shipping

Data empowers efficiency

Alongside the physical materials that traverse through interconnected and complex global supply chains, a wealth of critical data also must be transferred. When transporting dangerous goods, proper documentation and storage is essential to ensure that the products reach the proper destination while complying with local and federal regulations, with minimal risk to personnel and the environment.

"When we talk about dangerous goods, it really boils down to knowing what you're shipping, what mode you're using — road, air or sea — and who is doing the shipping. When it comes to what you're shipping, people don't often appreciate the effort that goes on in the background to get those products properly labeled and packaged. You may be making a brilliant product, but if you don't know how to ship it, it's just going to slow down the supply chain," says Mario Sagastume, vice president — software & customer success at Labelmaster (Chicago, Ill.; www.labelmaster.com).

Labelmaster has developed the Dangerous Good Information System (DGIS; Figure 1) to help with information management and shipment validation in the hazardous-materials sector. Shipment of dangerous materials often requires many additional steps when compared to non-regulated materials, and secure documentation of product quantity and its regulatory shipping name is crucial, even when only minute quantities of hazardous materials are present. "Some materials are not allowed to travel by air, or they cannot do so above a certain quantity, so shipments may need to be rerouted and schedules may be delayed," explains Sagastume. Another crucial step is training employees in understanding dangerous goods and the surrounding regulations. "As shippers, we need to know who is doing the shipment, when they will do it and how they will do it. Especially within multi-location users, where only one person may know the proper procedures, training and identifying the right people is key," he adds.

It is no secret that material shortages are leading to supply-chain disruptions, but these issues are also impacting the shipping and logistics providers. Especially in the shipment of dangerous goods, where specialized preparation and packaging is required, shortage of shipping materials is causing logistical challenges. "The toughest thing, from a supplier perspective right now, is that all of the labels that we produce are vetted by federal authorities, and they have certain requirements related to how labels should react under sunlight, or underwater for maritime transport, for instance, and to get the right adhesives and liners is quite challenging. Dangerous-goods packaging needs to be specially treated in a lot of cases as well, and that can also slow down the process," explains Sagastume.

Amidst all of these challenges, being adaptable and communicative is key. Customers must knowledgeably articulate their needs so that

FIGURE 2. A highly regionalized and representative database helps users to quickly conduct lifecycle assesments for a wide variety of chemical products and plastic materials

they can best scale their demand based on availability, or shift shipments from one location to another. "That flexibility is paramount to being able to survive these challenges — and also ramp up for the next wave of shortages or disruptions," adds Sagastume.

As more companies and consumers turn their focus to sustainability, manufacturers are also increasingly considering the climate impacts of their products over their full lifecycle. Since a significant portion of a company's emissions may come from supply-chain considerations, access to representative and comprehensive data at all points in a product's lifecycle is key to fully understanding the environmental implications of global production chains.

"As companies and entire industries become more sustainable, one of the hardest challenges — and greatest opportunities — they face is assessing and reducing environmental impacts in their supply chains. Chemical and plastic supply chains are particularly complex, so it is especially difficult to gather data and generate reliable assessments," explains Arne Kätelhön, CEO and co-founder of Carbon Minds GmbH (Cologne, Germany; www.carbon-minds.com). Carbon Minds is a data provider and consultancy that uses a proprietary model of the global chemical industry to offer lifecycle assessment data for over 1,000 chemicals and plastics in 190 geographical regions (Figure 2). "By modeling so many individual chemical production facilities, as well as how these plants are connected to each other through co-production and international trade, we generate a highly representative dataset of the environmental impacts of chemical and plastic supply chains. We are the only company that has modeled environmental impacts in global chemical supply chains on a supplier-specific level with full market coverage," Kätelhön says. Depending on where a company purchases its chemicals or plastics, the production pathways — and associated carbon footprint — can be very different, meaning that within any supply chain, there are very likely opportunities for impact reduction. Carbon Minds' supplier-specific carbon-footprint data indicate that, in the CPI, the difference in climate impact between an average supplier and a supplier with the lowest climate impact is around 38%, on average.

Carbon Minds is currently collaborating with chemicals intelligence firm ICIS (London, U.K.; www.icis.com) on an analytics tool using supplier- and plant-specific data to help companies assess, manage and reduce their supply-chain emissions and make informed sustainability-focused decisions. The company is also identifying gaps and expanding its data coverage. Such a comprehensive level of data accessibility is key to help companies understand their supply chain's climate impact. "Achieving net-zero chemicals and plastics will be a necessary step for companies in all sectors to achieve their net-zero emissions targets," emphasizes Kätelhön.

Blockchain supports traceability

Secure blockchain platforms are increasingly being leveraged to help validate supply-chain data at each node of the supply chain. This is particularly important for raw-material chains that must meet certain metrics for sustainability certifications. Such materials include recycled plastics, biofuels raw materials, battery metals and botanical ingredients, such as palm oils and cocoa.

Palm kernel oil. In May, BASF SE (Ludwigshafen, Germany; www.basf.com) announced a successful pilot proof-of-concept blockchain platform to establish greater traceability and authenticity of sustainable palm kernel oil (Figure 3). In a partnership with the technology company Bext360 (Golden, Colo.; www.bext360.com), the platform is designed to allow end users interested in responsible sourcing to trace palm ingredients using digitized and secure crypto-blockchain technology. Marcelo Lu, senior vice president, BASF Care Chemicals North America, says, "Using this technology platform, we believe that the consumer will be able to access greater traceability for every step along the palm value chain — directly from the farm through to the end consumer." Addressing transparency and traceability is an emerging trend, BASF says, and it plans to explore applying this blockchain technology to other ingredients and supply chains. Bext 360's digitized supply-chain platform was originally developed for tracing coffee, and has now been expanded to cover additional products, including cotton and textiles, minerals, recyclables and palm-based materials. The platform brings together data related to carbon intensity, Scope 3 emissions, customer payments and more at each node in the supply chain. Customers are increasingly asking for products that are sustainably produced, says Lu, and this blockchain platform provides validation of suppliers' practices. BASF is now producing an emollient product containing palm kernel oil that was traced using the blockchain platform.

Recycled polymers. In May, Neste Corp. (Espoo, Finland; www.neste.com) launched a project to apply the Circularise blockchain-based traceability software to trace renewable and recycled material flows. The software creates a digital twin for physical materials, which provides transparency

FIGURE 3. Using secure blockchain technology, BASF has been able to procure palm kernal oils exclusively from sustainably certified sources, with traceability back to the initial milling process

FIGURE 4. The EZ Flow chemical platform means that bulk heating and large volumes of diluents are not required during the transport of heavy crude

on where materials come from and how and where they were processed. The digital twin can also provide information on sustainability data, such as the carbon footprint of the materials or the products made from them.

Earlier this year, Toray Industries, Inc. (Tokyo, Japan; www.toray.com) announced a partnership with blockchain firm Soramitsu Co. (Tokyo; www.soramitsu.co.jp) to initiate a proof-of-concept trial for a traceability system for raw fiber materials made from recycled plastic bottles. Once the trial phase is complete in March 2023, Toray plans to deploy a similar traceability platform for other core fibers, resins and films.

Mitsui Chemicals, Inc. (Tokyo; www.mitsuichemicals.com) and IBM Japan, Ltd. (Tokyo) and are also developing a blockchain resource-circulation platform focused on circular plastics and recycling technologies. The platform will use IBM's technologies to visualize data related to the manufacturing, inspection and quality assurance of recycled plastics.

Eastman Chemical Co. (Kingsport, Tenn.; www.eastman.com) is collaborating with SAP SE (Walldorf, Germany; www.sap.com) to pilot SAP's GreenToken technology for the traceability of certified recycled content across the value chain using blockchain technology. This project will focus in particular on specialty plastics produced using Eastman's molecular recycling technologies.

Renewable fuels. In June, Gevo, Inc. (Englewood, Colo.; www.gevo.com) announced a partnership with Google Cloud to employ blockchain technology developed by Gevo's Verity Tracking division to track emissions data and provide measured verification of asset-level atmospheric emissions reductions, renewable energy-powered electricity for processing and land-use changes with soil quality and water impacts to support Gevo's production of low-carbon renewable fuels.

Last year, Acciona S.A. (Madrid, Spain; www.acciona.com) launched GreenH2chain, reportedly the world's first platform based on blockchain technology that guarantees the renewable origin of "green" hydrogen. According to Acciona, GreenH2chain provides information on hydrogen consumption, as well as data for calculating the offset CO_2 emissions that consumers avoid by using green energy.

Improved chemistry for crude oils

Transporting heavy crude oils, whether via pipelines, rail or trucks, has been fraught with difficulties due to a complex combination of physical and chemical properties. "The high density and high viscosity of extra-heavy crude oils are associated with the intermolecular forces between large, branched molecules, and the tendency of asphaltenes and paraffins to coalesce, producing aggregates of heavy hydrocarbons. Those agglomerations structurally compress the oil and reduce its relative volume," explains James Wood, project manager and principal scientist at the chemical engineering department of the Southwest Research Institute (SwRI; San Antonio, Tex.; www.swri.org). Overcoming these issues with flow resistance and aggregation typically involves the application of heat treatment during transport and the use of large volumes of diluents or drag-reducing agents. SwRI has developed a new chemical additive technology (Figure 4), called EZ Flow, which can significantly improve the properties of heavy crude oils, making the process of loading and unloading railcars and trucks less technically challenging, costly and time-intensive. "Mechanistically, the EZ Flow process reduces the intermolecular forces between and inside the agglomerates, promoting dispersion. The proprietary mixture of low-concentration (around 2 wt.%) chemical components, compared to other treatment options, optimizes the hydrodynamic cavitation of the heavy crude oil, which provides enough energy to enhance the chemical action without the need for bulk heating to break up aggregates," explains Wood, noting that EZ Flow treatments have demonstrated viscosity reductions of more than 60% in heavy crude oil.

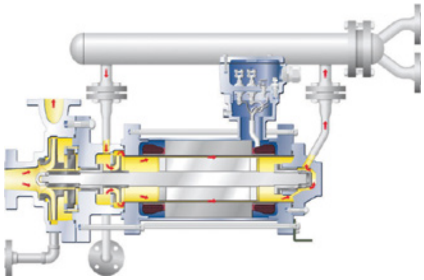
FIGURE 5. At the EZ Flow pilot facility, researchers screen chemical formulations and apply them to the hydrodynamic cavitation unit

Since EZ Flow only requires a single treatment prior to loading, explains Wood, there is no need to heat-treat heavy crudes during loading and unloading, and there is no need to dilute heavy crude with lighter hydrocarbons. Furthermore, since the EZ Flow additives consist of chemical species that are already found at petroleum refineries, including aromatic hydrocarbons and aliphatic solvents, there is no risk of adverse effects to refining equipment, such as corrosion. And compared to other additives, such as diluents, which are added in a large volume and often must be separated and recovered prior to transport, EZ Flow is a much less expensive option. SwRI is currently investigating EZ Flow's potential for treatment of additional products, including bitumen and other nonconventional oils at a small-scale pilot-plant unit with a 16-gal feed vessel and a high-speed cavitation device (Figure 5). ■

Mary Page Bailey

Focus on Pumps

LEWA



Hermetic-Pumpen

ITT

KSB

Track pump operation with this monitoring system

This company has developed Smart Monitoring for its ecoflow and triplex metering and process diaphragm pumps (photo). A combination of sensors integrated into the pump and software-based evaluation provides the user with comprehensive information on the performance and condition of the pumps. Malfunctions and wear development are detected before they lead to unscheduled shutdown. Around 90% of malfunctions (for example, overpressure in the hydraulics, worn plunger rings or incorrect closing behavior of valves) can be detected at an early stage, says the company. — *LEWA GmbH, Leonberg, Germany*
www.lewa.de

Canned-motor pumps for high-temperature applications

With leakage-free, durable canned-motor pumps, this company offers a comprehensive pump concept that has several advantages over other pumping technologies in high-temperature applications. The performance range covers fluid temperatures up to 480°C, system pressures up to 120 MPa and power ratings up to 690 kW. For high-temperature applications, the company offers two designs: canned motor pumps with externally cooled motors and canned motor pumps with adequate internally cooled motors (photo). The rotor lining is manufactured using the extrusion process and, as a nickel-based alloy, is an essential part of the highly efficient canned motor. In the flameproof encapsulated version, the canned motor complies with the explosion protection according to E.U. Directive 2014 / 34 / EU. — *Hermetic-Pumpen GmbH, Gundelfingen, Germany*
www.hermetic-pumpen.com

New wireless sensor expands machine monitoring

This company has launched a new generation of technology for its i-Alert total-machine-health monitoring ecosystem. The i-Alert3 sensor (photo) is designed to monitor and log the vibration and temperature of any rotating machine more quickly, accurately and cost-efficiently. It identifies and diagnoses mechanical and electrical failures in pumps, motors and other industrial machines before they occur by using a wider vibration frequency range. The i-Alert3 sensor upgrades i-Alert's condition-based monitoring solution, including the i-Alert mobile app, i-Alert gateway, and i-Alert AI Platform, with best-in-class automated machine-health diagnostics, says the company. Among the new features are a new magnetic flux sensor that includes electrical-health-analysis capabilities for motors. — *ITT, Inc, Seneca Falls, N.Y.*
www.itt.com

Pressure-booster systems for water supply applications

The new ready-to-connect pressure-booster systems of the Delta Macro type series (photo) are designed for large flowrates. The maximum flowrate per system is 960 m^3/h and the maximum pump head is 160 m as standard. The ready-to-connect units operate fully automatically and are equipped with between two and six Movitec high-efficiency centrifugal pumps. The systems' microprocessor control unit (Booster Command Pro+) starts and stops the pumps in line with demand, using either cascade control (F variant) or a frequency inverter for speed control (VC and SVP). A Modbus RTU interface provided as standard facilitates connection to external communication devices. — *KSB SE & Co. KGaA, Frankenthal, Germany*
www.ksb.com

A new range of vacuum pumps offer smart networking

Building on the GHS VSD+ range of variable-speed-driven (VSD) oil-injected screw vacuum pumps, this company has now introduced the new GHS 1402-2002 VSD+ series (photo, p. 17). The GHS 1402 - 2002 VSD+ is available in three pumping-speed classes. In rough vacuum applications, the oil-injected pumps deliver a continuously high pumping

Atlas Copco Vacuum Solutions

speed — from atmospheric pressure to ultimate pressure. The pump features a new oil-injected screw element with compression-optimization valves that allow for high pumping speeds at rough vacuum. It is equipped with the company's new vacuum controller, HEX@, making this pump ready for industry 4.0. — *Atlas Copco Vacuum Solutions, Cologne, Germany*
www.atlascopco.com

Immersion pumps with efficient motors

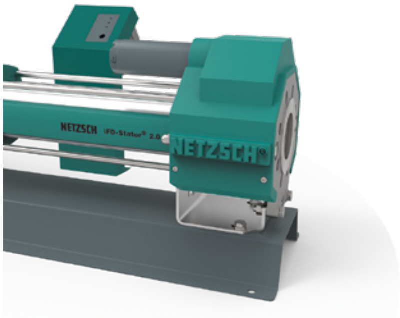
This company's Series 700, 800 and 900 immersion sump pumps (photo) are available with variable-frequency drive (VFD) motors. These vertical immersion sump pumps built for sump drainage, flood control and process drainage meet U.S. EPA and OSHA requirements. Depending on the speed selected, the VFDs provide the capability of varying flow and head performance from a vertical pump. These motors offer a cost-effective method of varying the pump performance as desired while conserving energy consumption. The Series 800, for example, provide heads to 230 ft and up to 3,000 gal/min flowrates, and operate at temperatures to 350°F and pit depths to 26 ft. These vertical, immersion sump pumps have a semiopen impeller, external adjustment, and come standard with NEMA C face motors (VFD motors are optional). — *Vertiflo Pump Company, Inc., Cincinnati, Ohio*
www.vertiflopump.com

Vertiflo Pump Company

An expanded line of explosion-proof Roots pumps

Pfeiffer Vacuum

Designed in accordance with the ATEX Directive (2014/34/EU1 and/or 1999/92/EC) with pressure-surge resistance of PN 16, Roots pumps from the OktaLine (photo) meet the very highest explosion-protection requirements. This series of pumps is now expanded, with pumping speeds ranging from 280 to 8,100 m^3/h. With their magnetic coupling, OktaLine pumps are hermetically sealed and achieve extremely low leak rates of 10^{-6} Pa m^3/s. Compared to pumps with shaft seals, the OktaLine's magnetic coupling achieves up to 20% lower operating costs and considerably reduced maintenance costs, says the company. The magnetic coupling eliminates the need for shaft seals. OktaLine ATEX pumps are pressure-surge resistant up to 1,600 kPa. — *Pfeiffer Vacuum GmbH, Asslar, Germany*
www.pfeiffer-vacuum.com



Netzsch Pumpen & Systeme

Pompetravaini

Finish Thompson

Industrial Flow Solutions

Volkmann USA

Smart pump saves up to 30% in energy costs

The new xLC-select stator-adjustment system (photo) is said to be the world's first autonomous system that automatically readjusts the pump, and thus reduces energy consumption. The xLC-select stator-adjustment system is an accessory for progressing cavity pumps that, based on algorithms, recognizes the optimal efficiency of the pump completely independently and adjusts the stator optimally to it. Not only are energy costs reduced by up to 30%, but the CO_2 footprint is also significantly reduced, says the company. — *Netzsch Pumpen & Systeme GmbH, Waldkraiburg, Germany*
www.pumps-systems.netzsch.com

A range of centrifugal pumps for the CPI

This company offers a complete range of centrifugal pumps for the chemical process industries (CPI; photo). The pumps are ISO-2858 and ISO-5199 certified and can be offered in numerous configurations in terms of materials and mechanical-sealing configurations, virtually covering the entire range of API 682 standards used in the chemical and petrochemical industries. Pumps can be supplied with different impeller designs to get the maximum performance considering the pumped fluid characteristics. Magnetic drives and special configurations are available as options. A specific series for hot-oil pumping up to 365°C is ready for delivery. — *Pompetravaini, Castano Primo (MI), Italy*
www.pompetravaini.com

A new model of non-metallic AODD pumps

The new FTI Air FT025 1/4-in. air-operated, double-diaphragm (AODD) pump is manufactured from unfilled polypropylene (PP), unfilled polyvinylidene fluoride (PVDF) or conductive carbon-filled PP and features Santoprene or polytetrafluoroethylene (PTFE) diaphragms for maximum chemical compatibility. It offers 5.8 gal/min (22 L/min) maximum flow. The new 1/4-in. AODD plastic pump features a unique lubrication-free, non-stalling air valve that is simple, rugged and reliable, requiring no separate or mechanical pilot valve. The air valve contains fewer parts than alternatives, reducing maintenance time and costs. The pump also features a durable stainless-steel airline connection for maximum reliability. The FTI Air Model FT025 pump works with many fluids, including acids and bases, plating solutions, wastewater and solvents. — *Finish Thompson Inc., Erie, Pa*.
www.ftiair.com

Pumping system manages wastewater lift stations

The OverWatch direct inline pump system (photo) lifts influent at the point of entry, eliminating the wet well. Effluent is contained, eliminating odors and reducing maintenance. The stainless-steel body is designed to withstand the effects of corrosion from harsh materials and solutions, making OverWatch suitable for the municipal, industrial and commercial industries. The patented system lifts effluent directly at the point of entry, and a patented impeller/shredder cuts fibrous materials and other solids. Variable-speed drives are available for continuous modulated pumping directly from the effluent inlet to save energy. The system averts dangerous gases, such as H_2S, and eliminates smells, while preventing sand and grease from accumulating. — *Industrial Flow Solutions, New Haven, Conn.*
www.flowsolutions.com

Vacuum technology supports explosion-proof conveying

The Multijector vacuum pumps (photo) feature patented technology based on the venturi principle that generates the high amounts of suction air and negative pressure needed to transfer powders and other bulk solids gently in dense phase. The vacuum pumps operate with compressed air, while eliminating the rotating parts, motors, lubricants and heat and ignition sources common to electromechanical pumps. A key part of removing any potential sources of ignition, the Multijector vacuum pumps allow explosion-proof, ATEX-certified conveying, even when conveying fine, ignitable powders and combustible dusts. The line of Multijector vacuum pumps comprises 12 different models in a choice of materials and optional configurations. The Multijector G Series four-stage ejector vacuum

pumps and the Multijector MX Series three-stage ejector vacuum pumps offer a wide range of airflows to meet the requirements of each pneumatic-vacuum-conveying system. — *Volkmann USA, Bristol, Pa.*
www.volkmannusa.com

A new model added to this pump range

Following the earlier introduction of the CR 185 and CR 215 pumps, this company recently added the CR 255 pump (photo), with flow range capacities up to 240, 280 and 320 m^3/h respectively. The new hydraulic design improves everything from impeller and guide vanes to inlet, discharge port, sleeve and diffuser, taking current energy efficiency and performance standards for vertical multi-stage inline pumps to the next level. To ensure maximum efficiency, the hydraulic design of the new CR range has been optimized to move liquids with as little friction and turbulence as possible, says the company. The shaft seal of the CR pumps is developed in-house and is available

Grundfos

in various material combinations to suit different liquid, pressure and temperature requirements. Thanks to its balanced design, the CR seal can withstand a great amount of pressure and can expect a longer service life compared to other large pumps. The pumps also are designed to reduce the risk of cavitation and increase the robustness and lifecycle of the pump. — *Grundfos, Bjerringbro, Denmark*
www.grundfos.com

Save energy with this new synchronous motor

With ratings at IE 4 and IE 5, the SynRA (photo) is a patent-pending synchronous motor that, when paired with the company's ID300 Perfectspeed integrated drive, is said to offer one of the highest ef-

Nidec Motor

ficiencies available for today's industrial and commercial pumping and HVAC equipment. In addition to significant energy savings, this new technology offers the advantage of easy motor replacement, without having to install an entirely new system and controls, saving time and money. SynRA provides the operating benefit of a pure synchronous reluctance motor, and suitability benefit from a simple volts/Hz drive. The product's Smart Technology results in less wear and tear on blower or pump systems by matching application demands with variable speed. — *Nidec Motor Corp., St. Louis, Mo.*
www.usmotors.com ■

Gerald Ondrey

Alternating-Current Induction Motors

Department Editor: Scott Jenkins

Alternating-current (a.c.) induction motors are widely used throughout the chemical process industries (CPI) and other manufacturing sectors to convert electrical energy into mechanical energy to power rotating equipment, such as centrifugal pumps, compressors and fans, as well as other industrial machinery. This one-page reference provides information on the construction and operation of three-phase induction motors (Figure 1).

Motor components

The basic construction of a typical industrial a.c. induction motor includes the following elements: rotor, stator, stator windings and enclosure.

Rotor. The rotor has an iron core made from a cylinder-shaped stack of laminated rings around a motor shaft to which it is attached. The rotor has conducting end caps on either end and conducting bars that run through slots in the laminated metal stack between the end caps. The assembly rotates inside the stator on bearings, which ensure that the rotor remains centrally positioned with the stator. The appearance of the rotor and conducting bars gives rise to the name "squirrel-cage motor."

Stator. The stator is made from a series of stacked steel sheets that are ring-shaped and encircle the rotor, while allowing the rotor to move freely. The stacked metal slices are laminated with insulating material and have spaces cut out around their diameter to accommodate the copper windings.

Windings. Windings made from copper wire are distributed in the slots on the interior of the stator to carry the supply electrical current that will induce a magnetic field that will penetrate the rotor inside.

Enclosure. The enclosure, consisting of a frame and end bells, protects the motor. There are several types of enclosures for different applications, as designated by the National Electrical Manufacturers Association (NEMA; Rosslyn, Va.; www.nema.org), a trade association and standards-making body. The four main NEMA enclosures are the following: open, drip-proof (ODP) enclosures; totally enclosed, non-ventilated (TENV); totally enclosed, fan-cooled (TEFC); and totally enclosed, blower-cooled (TEBC) motors.

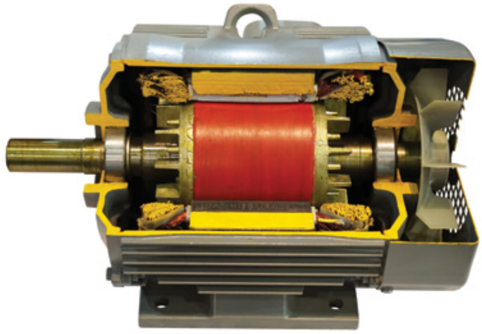


FIGURE 1. In this cutaway image of the interior of an electrical induction motor, the rotor can be seen inside the stator, which surrounds it

Induction motor operation

With correct design of the stator windings and stator slots, applying alternating current to the stator will generate a rotating magnetic field. When electrical current is applied, the stator produces a rotating magnetic field needed to rotate the motor shaft. Typically, three-phase a.c. electric power is supplied to the stator so that the three phases are electrically separated from each other by 120 deg.

Meanwhile, the rotor sits inside the stator core and its design gives it the ability to conduct electromagnetic current. As the rotating magnetic field moves about the rotor, it induces voltage in the conducting bars of the rotor. Because of the conductive end caps on each end of the rotor, current can flow though the rotor bars. The rotor then produces a magnetic field opposed to that of the stator. The opposing magnetic fields set up a situation where the opposite poles of the rotor and stator attract each other while the like poles repel. As the stator's magnetic field rotates, the rotor chases it, driven by the attractive and repellent magnetic forces.

Motor terminology

The following terms are useful for understanding the real-world operation of an induction motor.

Magnetic poles. The stator can be designed to have a varying number of magnetic poles around the stator body. The number of poles has an impact on the speed and torque of the motor. For a smaller number of poles, the speed of the rotating magnetic field is faster, but the torque is lower. Adding magnetic poles lowers the speed of the magnetic field, but increases the level of torque that is possible for the motor to generate. The manufacturing cost for the motor is higher for larger numbers of poles, so most motors are two- or four-pole motors.

Synchronous speed. This is the speed of the rotating magnetic field in the stator. Synchronous speed is calculated by the equation $N_a = 120f/P$, where f is the frequency of the a.c. supplied to the stator and P is the number of motor poles. For example, the synchronous speed of a four-pole motor powered by 60-Hz a.c. current would be 1,800 rpm.

Rated speed. The rated speed is the rotational velocity of the rotor inside the motor housing. The rated speed is always less than the synchronous speed because the rotor always rotates slower than magnetic field of the stator. In fact, the rotation speed of the rotor must be lower than the synchronous speed or else there would be no induction and the rotor would not be able to create a magnetic field.

Slip. The slip is the difference between the speed of the rotating magnetic field of the stator and the mechanical speed of the rotating rotor assembly. The size of the slip depends on the load that is on the motor. For a larger load on the motor, the slip will be greater than for smaller loads.

Torque. The term torque refers to the rotational force generated by the rotating motor. Induction motors draw more current as the load is increased, and consequently produce more torque. ■

Editor's note: Some material for this column is from Yaskawa America Inc., Induction Motor Basics, video e-learning module, accessed at www.yaskawa.com/support-training/training/elearning-curriculum

A Quick Diagnosis Makes a Short Assignment

Henry Kister shares lessons learned from troubleshooting distillation towers

On an assignment to troubleshoot a vacuum tower for a petroleum refinery, my team was tasked to "run simulations to determine why the heavy vacuum gas oil (HVGO) has a very dark color."

We traveled to the site and met with the plant personnel in a large meeting room. The plant's process engineers carried in large volumes of computer output. I was not sure what additional simulations they wanted us to do that they had not already done.

During the meeting, we discussed the tower, the plant engineers' experiences and their analysis. They had already performed a very extensive simulation study. The afternoon agenda focused on contract discussion. The project manager could not make it, so I had to fill in for him.

I was traveling with a young engineer, and did not need him to attend the contract discussion. So, I dreamt up something for him to do, to help answer a question that I had raised during the meeting, which had not been fully answered.

"Why don't you go with the unit engineer to the unit. On the wash stream going to the tower, downstream of the filter and the control valve, the P&I [process and instrumentation diagram] shows a pressure gage. Can you please go there and get me the reading?"

The pressure gage in that location (Figure 1) is an invaluable troubleshooting tool. Neglecting line losses, the pressure balance is such that the pressure at the gage equals the tower pressure (which is known from the tower pressure transmitters, and is usually very low because this is a vacuum tower), plus the liquid head to the column entry (that can be calculated from the elevation difference), plus the pressure drop across the spray nozzles that distribute liquid to the wash bed. Subtracting the tower pressure and the liquid head from the pressure-gage reading gives the pressure drop across the spray nozzles.

These nozzles are typically designed for a 10–20-psi pressure drop. An even better evaluation can be obtained by comparing the measured pressure drop with the pressure drop calculated from the spray-vendor's catalog based on the metered wash flowrate.

About half an hour later, the engineers returned.

"What does it read?" I asked.

"160 psig."

Oops. I turned to them.

"I apologize. I misled you. Please go again, but this time stop at the instrument shop on the way to the tower. Ask the instrument technician for a new pressure gage, and make sure that the instrument technician swears that it works. Go back to the same spot. Remove this old pressure gage that obviously is "kaput". Replace it by the new gage, and get me a decent reading this time."

So off they went. They came back an hour later.

"What does the new one read?" I inquired.

"150 psig."

At that moment, everyone realized that the problem was not the gage. To give this kind of pressure drop, the sprays had to be plugged solid. With plugged sprays, liquid is not distributed — the bed cokes, and the HVGO goes dark. That was the end of story. There was no need for any simulations. Our assignment ended right then.

The takeaway: One good measurement is worth more than thousands of calculations. ■

Edited by Dorothy Lozowski

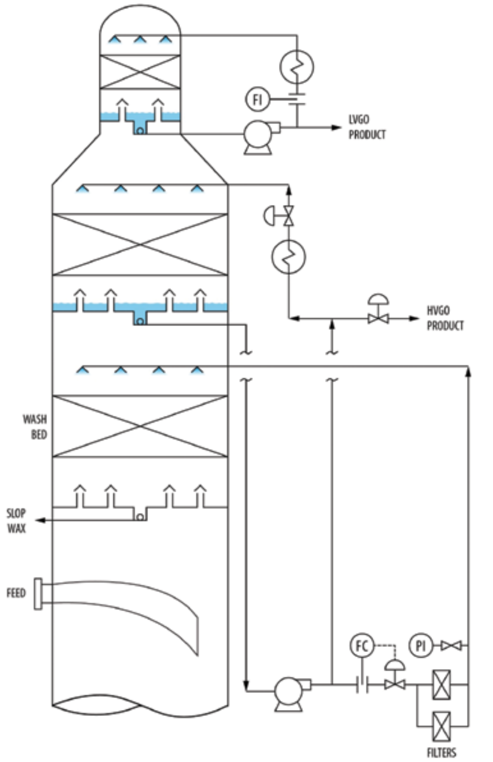


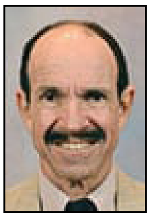
FIGURE 1. The petroleum refinery's vacuum tower is depicted in this diagram

About the Tower Doctor

"The Tower Doctor" is the honorary title bestowed upon the author of this article in 2002 by Richard Darton, professor of Engineering in Oxford University and chair of the European Distillation Network. "When a tower is not well," says Darton, "people call Henry to diagnose the illness and find a remedy. He arrives with his doctor's bag, examines the patient-tower, measures its temperature and pulse, gets radiography to get an inside look. Then comes his diagnosis and cure. Towers treated by Henry mostly get better very quickly."

Being son to two medical doctors who were blessed with phenomenal diagnosis ability, the author aspired to live up to this special honorary title. Like with medical doctors, some illnesses were a struggle to diagnose, others were easier. All were exciting. This column will reminisce through some of the more entertaining cases. They may not have seemed entertaining at the time, but looking back at them, they leave unforgettable memories and raise a smile or two. One great aspect of being a tower doctor, one gets to work with and learn from some of the greatest engineers and operators that contributed so much to the chemical industry. We hope that this column can pass some of the fun, excitement and lessons learned to future troubleshooters and tower doctors.

Author



Henry Z. Kister is a senior fellow and the director of fractionation technology at Fluor Corp. (3 Polaris Way, Aliso Viejo, CA; Phone: 949-349-4679; Email: henry.kister@fluor.com). He has over 35 years of experience in design, troubleshooting, revamping, field consulting, control and startup of fractionation processes and equipment. Kister is the author of three books, the distillation equipment chapter in Perry's Handbook, and over 130 articles, and has taught the IChemE-sponsored "Practical Distillation Technology" course more than 530 times in 26 countries. A recipient of several awards, Kister obtained his B.E. and M.E. degrees from the University of New South Wales in Australia. He is a member of the NAE, a Fellow of IChemE and AIChE, and serves on the FRI Technical Advisory and Design Practices Committees.

Atmospheric Pressure Releases: Which Require Dispersion Modeling?

Dispersion modeling of atmospheric releases from pressure-relief valves and other sources can be time-consuming. Follow this screening process to categorize which installations require detailed modeling and focus effort where it is most consequential

John Burgess, Dustin Smith and Thuc Ngo
Smith & Burgess Process Safety Consulting

IN BRIEF

DESIGNED ATMOSPHERIC RELEASES
NON-FLAMMABLE, NON-TOXIC FLUID
FLAMMABLE/ COMBUSTIBLE FLUID
QUANTITATIVE ANALYSIS
TOXIC FLUIDS
CONCLUDING REMARKS

The safe design of atmospheric relief/venting systems is imperative in chemical and petrochemical facilities when pressure-relief systems are designed to release flammable or toxic materials directly to the atmosphere (as compared to a release to a flare or incinerator). Many facilities have the potential for atmospheric releases, either from existing installations or new designs that require simple discharge systems. Recent incidents and regulatory pressure have many facility designers asking the following questions:

- How many relief valves in the facility vent to the atmosphere?
- Are these relief valves safe?
- Can we ensure that the relief installations meet the requirements for RAGAGEP (recognized and generally accepted good engineering practices)?

To ensure that atmospheric discharges terminate at a "safe location," as required by good engineering practices (for example, the American Society of Mechanical Engineers Boiler and Pressure Vessel Codes, section VIII UG-135(f)), engineers and designers should follow a systematic decision-making process. In this article, a safe location is an installation that meets the criteria in the American Petroleum Institute Standard 521 (Pressure-Relieving and Depressurizing Systems) [*1*] but may not meet more stringent requirements or environmental rules.

To determine the safety of atmospheric releases from pressure-relief valves, facilities can use industry-available modeling tools (such as DNV Phast, Baker-Risk SafeSite3G and so on) to perform dispersion modeling of the releases for consequence analysis. However, modeling every atmospheric release can become overwhelming and produce a large volume of data without adding value. Therefore, a more practical solution may be to apply a simple screening process that will categorize safe installations based on RAGAGEP practices. Following the screening process allows time and effort to be focused on those installations that fail simple screening and that require detailed modeling.

This article consolidates the simplified methods in API 521, and provides a decision-making process such that typical plant engineers with everyday tools can screen

FIGURE 1. Designed releases of materials to the atmosphere can occur from pressure-relief valves, such as the one shown here, and other equipment

most atmospheric releases. The article can be used as the basis for screening the designed releases from atmospheric relief devices at new and existing facilities. In addition, this article provides qualitative, quantitative and semi-quantitative methods to screen the atmospheric release based on the hazardous properties of the discharged fluids, including non-flammable/combustible/toxic, flammable/combustible, and toxic materials.

Detailed dispersion modeling was performed to validate the results of the simplified equations presented in this article. While there are always rare circumstances that can occur, under the most common conditions for processing hydrocarbon streams, the methods in this article are conservative and can be used to screen atmospheric relief device installations. However, each installation is different and engineering judgement must be used to ensure that the specific installation meets all government and company requirements. There is no attempt here to create a methodology that will be applicable to all possible installations or discharge compositions. The user takes responsibility for how the methodologies proposed here are executed and interpreted. Environmental impacts and permit compliance is outside the scope of this article. However, these methods may help achieve compliance with the Risk Management Plan (RMP; U.S. Environmental Protection Agency) requirements in the U.S.

Designed atmospheric releases

Generally, in the chemical process industries (CPI), there are two major risks associated with atmospheric discharges: (1) the generation of a flammable or explosive mixture, and (2) the accumulation of toxic materials at a concentration level that may cause harm. Therefore, this article consolidates the simplified methods in API STD 521 to screen the atmospheric release based on the hazardous properties of the discharged fluids including flammability, combustibility, physical effects from non-flammable/non-toxic materials, and toxicity.

Methods and designs necessary to comply with environmental regulations are not discussed and must be independently verified.

The focus here is on designed releases from atmospheric pressure relief devices, rather than "accidental" releases from loss of containment. Consider the following two cases:

1. An amine regenerator overpressures and the relief device works as designed. This system is in a gas plant and the relief device's final disposition is from an atmospheric collection system. The resulting vapor cloud results in H_2S area monitors activating and the evacuation of all non-essential personnel from the site. The unit also shuts down.

2. A forklift driver delivers equipment near the amine regenerator and backs into piping, resulting in a leak from a control valve station. This leak creates a vapor cloud that activates H_2S monitors. Consequently, all non-essential personnel from the site are evacuated and the unit shuts down.

Which case is worse? Arguably both cases could have been prevented with better engineering design, but in the first scenario the overpressure system functioned as designed and yet the facility was evacuated. This article will help engineers design installations such that the first scenario should not occur. The article focuses on designed releases (such as relief-device tail piping), as compared to facility siting concerns associated with loss of containment scenarios (such as vessel ruptures).

Atmospheric venting is designed into many petrochemical and refining facilities. Generally, designed or planned atmospheric releases come from several sources:

Control systems. Backpressure regulators, compressor stability control schemes and emergency shutdown devices can discharge to the atmosphere.

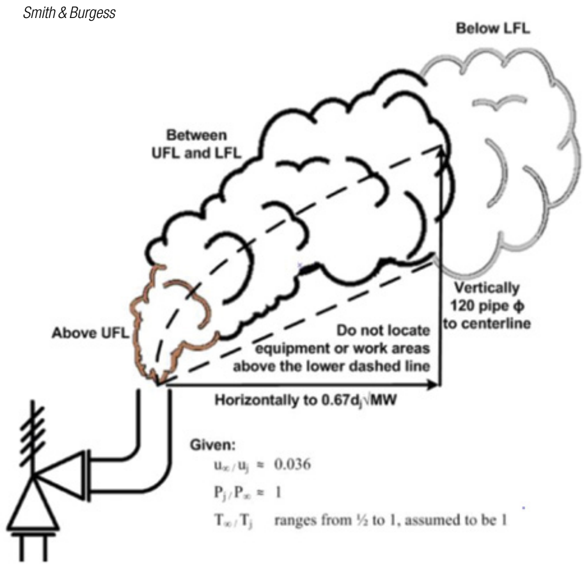


FIGURE 2. After the atmospheric release of a vapor-phase material, the downwind distance that the material will travel at concentrations between its UFL and LFL must be determined

Pressure-relief devices. Pressure relief valves, rupture disks, and conservation vents can all have installations that discharge the effluent directly to the atmosphere.

Atmospheric collections systems. These systems can range from the collection of one or two relief devices into a single vent stack to systems as complex as flare systems terminating with a vent instead of a flare tip. Special considerations are required for the analysis of the vent, especially in global relief scenarios, as there is no designed means to burn the effluent.

Flare systems. Flare systems are designed to capture the effluent from the facility, remove entrained liquids, and burn the remaining vapor.

In addition to the listed vents, many other vent sources may occur in a facility. For example, in addition to venting from the discharge location, relief devices may vent from a broken bellows or pilot-operation system. Open pipe vents may occur (typically steam or other inert systems), but often there are process vents from normally closed isolation valves or through misaligned isolation valves. Low-pressure tank vents (pressure-vacuum vents, gooseneck vents, or otherwise) typically vent directly to atmosphere.

Often, these systems can be designed safely with proper consideration for the hazards of the fluid and for the design of the vent or flare.

However, the focus of this article is on the direct discharge of atmospheric relief devices through the tail pipe (as opposed to venting through a broken bellows).

To evaluate whether the discharge of an atmospheric relief device occurs to a "safe location," the engineers and designs should follow two steps:

Step 1. Determine the possible hazards of discharged fluids that are expected to release from the relief devices. This includes whether the fluid is flammable/combustible, toxic, or neither. The potential fluid discharges should be based on a thorough pressure-relief system analysis. Users are cautioned that relief devices located on equipment primarily containing no hazardous fluid might still have the potential for hazardous fluid discharge.

Step 2. Depending on the hazardous fluid type, the engineers/designers can apply the appropriate screening methods, as listed in the following sections.

Non-flammable, non-toxic fluid

Usually, these are the safest systems to discharge to atmosphere, since they rarely result in large-scale harm. When analyzing the location of the discharge, consider the following:

Effects on personnel. The effluent from a vent cannot be universally determined "safe" just because it doesn't burn and is non-toxic. If the effluent stream could come into contact with personnel or equipment, the following criteria should be considered:

- *Impingement*. The effluent stream contacting individuals or equipment could cause injury or damage. High-velocity fluid also has the potential to injure individuals who may be in the discharge path. When analyzing the impingement of an effluent on personnel, the engineer should analyze the immediate disposition of the fluid, as well as the subsequent movement of the fluid. The analysis should include nearby work areas, walkways, ladders and other areas designed for occupancy. Direct contact of a hot fluid, such as steam or water, could cause burns. Vapor liquid mixtures or those which may condense (for example, saturated steam) may result in the liquids "raining" down, even if the discharge is directed upwards.
- *Oxygen-deficient atmosphere*. A large release of a simple asphyxiant into a building or confined area could dilute the oxygen in the atmosphere and thus make the area uninhabitable. Common industrial gases, like nitrogen, helium and argon, are classified as simple asphyxiants.
- *Emergency operations.* The ability of operators to safely perform emergency procedures during a release should be considered. If a nearby isolation valve requires manual operation during a release, the designer needs to consider the effect of the release on the operator.
- *Noise.* Depending on the characteristics of the vent and effluent, the noise generated from a release may be loud enough that plant personnel, even with hearing protection, may not be able to work in the area.

Public relations. Another consideration is the effect the release may have on the public. The designer needs to consider if a system will routinely release. Releases should be reviewed for the potential to form "clouds," loud noises or odors. Any of these factors may interfere with operations or cause concern with the public.

Flammable/combustible fluids

These releases require more engineering review than non-flammable/non-toxic releases. The discharge of potentially flammable material to atmosphere is generally not preferred. However, the risks associated with atmospheric releases can be minimized by designing the system carefully. An extensive review of incident reports from various databases, including the Major Accident Reporting System (MARS), Major Hazard Incident Data Service (MHIDAS), and the National Fire Information Reporting System (NFIRS), concludes that incidents associated with atmospheric releases directly from relief devices, which are not part of a collection header or blowdown drum, are very rare. Therefore, with proper design that follows good engineering practices, facilities can ensure relief devices discharging flammable fluid to atmosphere are discharging to a "safe location."

For systems with flammable or combustible fluids, or both, system designers should consider the following analysis (in addition to the criteria for the non-flammable/combustible and non-toxic fluids):

Fluid phases. For vapor releases, a release of flammable material begins at the process concentration. Then, as the fluid in the piping exits and begins to mix with the atmosphere, the concentration drops through the upper flammable limit (UFL), and at some point is diluted to below the lower flammable limit (LFL). After the concentration drops below the LFL, the effluent ceases to be a fire or explosion risk. All releases of potentially flammable material must be reviewed to ensure that the fluid has safely passed through the LFL before the "cloud" reaches a point of interest (such as an ignition source, grade, platform, equipment and so on).

Scenarios that could release flammable liquids or solids to atmosphere are generally not acceptable and require mitigation. The release case needs to be mitigated through one of the following mechanisms:

1. Dedicated safety instrumentation (compliant with ISA S-84 or other applicable standard) to the point that the potential for release is no longer credible
2. The relief system design must ensure that the liquid and solids are contained and are not vented (for example, a blowdown drum or tank) to the atmosphere.

At the time of writing this article, not all commercially available dispersion-modeling software accurately predicts the dispersion of liquids and solids. Unless engineers and plant designers can validate the model findings, the validity of the predicted flammable concentrations for liquid and solid releases may not be useful.

Installation. Relief-device exit piping should be pointed vertically upward. With proper design of the device, discharge configuration has historically been a safe means of disposing flammable vapors.

Semi-quantitative analysis. The primary concern when analyzing flammable atmospheric releases is the potential to form a flammable cloud near ignition sources or workers. API STD 521 7th edition, section 5.8 provides a series of guidelines to determine if a relief device discharging flammable vapor to atmosphere is acceptable based on the "jet" momentum and velocity mixing effects of the discharge. The greater the exit velocity, the more turbulently the material mixes with air. This results in the concentration of the released material quickly decreasing to below the LFL. Even in releases where there are high winds present, higher velocities from vertically oriented vents are directed more vertically than horizontally.

The following is a semi-quantitative method (in accordance with API STD 521 7th edition in §5.8) to determine if a release is to a "safe location." To be considered safe, an affirmative response to all of the following is required:

- The molecular weight (MW) of the fluid is less than 80 g/mol for a hydrocarbon release (additional information below in Note 1)
- The exit velocity is greater than 100 ft/s (additional information below in Note 2)
- The ratio of the exit velocity to wind speed is greater than 10
- There is no equipment or work areas at or above the release point horizontally for 50 ft
- The relief/jet temperatures are close to or above the expected atmospheric temperatures
- The qualitative considerations from the non-flammable/combustible and non-toxic fluids section have been reviewed

Note 1. For hydrocarbon releases with a MW greater than approximately 100 g/mol, there is an increasing chance for condensation. Relief streams continuing with other fluids may condense as well. Depending on the velocities and concentration of the fluid at the point which the temperature drops, an explosive atmosphere may be formed. (More information on this topic can be found in Refs. 2 and 3.

Note 2. Relief devices are not expected to flow at rated capacity all of the time. The guidance in Section 5.8 of API STD 521 7th edition says to consider that relief devices close at approximately 25% of the rated capacity. Thus, a designer may need to consider a range of flowrates for an installation based on the results of the relief-systems analysis.

If the installation does not meet all the listed criteria above, consider the quantitative analysis procedure in the following section.

Quantitative analysis

This section presents the simplified analysis presented in API STD 521 7th edition Figures 8 and 9. The figures are condensed into a simple equation to calculate the horizontal downwind distance that the flammable vapor may travel prior to dilution below LFL concentration. For an atmospheric relief device to be considered to discharge to a "safe location," no potential ignition source should be located within that radius at or above the release elevation .

Figure 2 depicts an atmospheric

release of a flammable vapor stream as the concentration of effluent starts above the UFL, is then within the flammability limits, and finally drops below the LFL. The vertical and horizontal distances to below the LFL are based on API STD 521 7th edition Figure 8 and Figure 9, respectively.

The data shown in API STD 521 7th edition Figure 9 were cubic feet to develop an equation to calculate horizontal downwind distance to LFL. The maximum downwind horizontal distance from jet exit to lean-flammability concentration limit for petroleum gases can be expressed as follows:

$$\frac{x}{\frac{d_j}{12}\sqrt{\rho_j/\rho_\infty}} = 19{,}301\left(\frac{u_\infty}{u_j}\right)^3 - 5{,}660\left(\frac{u_\infty}{u_j}\right)^2 + 334\left(\frac{u_\infty}{u_j}\right) + 37.9 \quad (1)$$

Where:
x is the horizontal distance downwind to the LFL for a hydrocarbon release, ft
d_j is the inside diameter of the jet release exit, in.
ρ_j is the density of the fluid just inside the tip exit, lb/ft^3
ρ_∞ is the density of the ambient air, lb/ft^3
u_j is the fluid jet exit velocity, ft/s
u_∞ is the wind speed, ft/s

For an ideal gas,

$$\rho = \frac{MW\,P}{T\,R}; \quad thus,\ \frac{\rho_j}{\rho_\infty} = \frac{MW_j P_j}{T_j R}\cdot\frac{T_\infty R}{MW_\infty P_\infty} = \left(\frac{MW_j}{28.8}\frac{T_\infty}{T_j}\frac{P_j}{P_\infty}\right) \quad (2)$$

Where:
MW_j is the molecular weight of the jet release fluid
MW_∞ is the molecular weight of the atmosphere, 28.8 g/mol
P_j is the pressure of the fluid just inside the tip exit, which is typically atmospheric pressure in the case of a pipe exit, psia
P_∞ is the pressure of the ambient air / atmosphere, psia
T_j is the fluid jet exit temperature,°R
T_∞ is the temperature of the ambient air / atmosphere, °R

The following is the result of substituting Equation (2) into Equation (1) and solving for the distance downwind to the lower flammability limit:

$$\frac{x}{\frac{d_j}{12}\sqrt{\rho_j/\rho_\infty}} = \frac{x}{\frac{d_j}{12}\sqrt{\left(\frac{MW_j}{28.8}\frac{T_\infty}{T_j}\frac{P_j}{P_\infty}\right)}} \quad (3)$$

$$x = \frac{d_j}{12}\sqrt{\left(\frac{MW_j}{28.8}\frac{T_\infty}{T_j}\frac{P_j}{P_\infty}\right)}\left(19{,}301\left(\frac{u_\infty}{u_j}\right)^3 - 5{,}660\left(\frac{u_\infty}{u_j}\right)^2 + 334\left(\frac{u_\infty}{u_j}\right) + 37.9\right) \quad (4)$$

With the following conservative assumptions, Equation (4) can be further simplified:
$u_\infty/u_j \approx 0.036$, the maximum downwind extents of the LFL
$P_j/P_\infty \approx 1$, the pressure at the maximum vent velocity is near atmospheric pressure
T_∞/T_j ranges from 0.5 to 1, and is assumed to be 1. For an atmospheric temperature of 70 °F, the release temperature would be limited between 70°F and 600°F or less for this assumption.

$$x = \frac{d_j}{12}\left(\sqrt{\frac{MW_j}{28.8}}\right)(43.5) = 0.67 d_j\sqrt{MW_j} \quad (5)$$

Engineers and designers can use Equation (5) to quickly calculate horizontal downwind distance to LFL concentration.

Two hundred sixteen unique dispersion models were performed in DNV PHAST to validate Equation (5). Each dispersion model was run with three different weather conditions. The conditions for the different releases are shown in Table 2. Each of the cases in Table 2 were run for Crosby 1½G3, 4M6 and 6Q8 relief devices. The discharge point has the same pipe diameter as the relief-device outlet. The wind speeds used were 3.5 ft/s, 5 ft/s and 10 ft/s, all with an atmospheric stability class of D. The cases were run at the full capacity of the relief device (as determined by PHAST) and 25% of the rated relief device capacity.

TABLE 1. FLUID CONDITIONS FOR THE DISPERSION MODELS RUN TO COMPARE AGAINST EQUATION (5)

Fluid	Pressure, psig	Cold, °F	Hot, °F
Ethane	50	0	100
Ethane	250	50	100
n-Pentane	50	200	400
n-Pentane	250	325	400
n-Octane	50	375	600
n-Octane	250	525	600

For each of the cases reviewed, Equation (5) predicted the extent of the flammable zone to be 1.3 to 3.0 times farther than the horizontal distance predicted by the PHAST modeling. Also, for the smaller-diameter vents with lower-MW fluids, Equation (5) tended to overpredict the horizontal distance by 1.3 times more than the dispersion modeling. For the larger vents with higher-MW fluids, Equation (5) tended to overpredict the horizontal distance by as much as three times compared to the dispersion modeling.

The dispersion modeling to test Equation (5) showed that as much as 1/6 to 1/3 of the cloud height may be between the cloud centerline and the lowest point where the LFL is present. As such, detailed dispersion modeling should be completed if there is equipment above the discharge location within the LFL horizontal distance predicted by either Equation (4) or Equation (5).

Note that this method does not consider the effects of condensation of the effluent stream, which must be considered by the relief system engineer/designer (see Note 2 in the previous section).

Potential for ignition. API STD 521 requires the system designer to review the potential effects of thermal radiation on workers if the release stream is ignited. This is the case even when there is no potential ignition source within the flammable cloud. Ignition of the effluent stream may still occur (for example, because of static electricity, lighting, autoignition and so on) and the impacts of thermal radiation exposure should be considered. Some facilities install the ability to inject emergency steam into the tail pipes of relief devices to snuff out flames should the effluent catch fire.

TABLE 2. SOURCES OF EXPOSURE CONCENTRATIONS FROM VARIOUS AGENCIES

Org	Guidance	Target	Definition
EPA	AEGL	Public exposure	The Acute Exposure Guideline Levels is a three-tier guideline for emergency response for a time period between 10 minutes and 8 hours
AIHA	ERPG	Public exposure	The Emergency Response Planning Guideline is a three-tier planning guideline for emergency response
NIOSH	REL & IDLH	Worker exposure	The NIOSH recommended exposure limits (REL) calculated based on a time-weighted average (TWA) for a 10-hour work day, short term exposure limit (STEL) for 15 minutes and a ceiling (C) that must not be exceeded
OSHA	PEL	Worker exposure	OSHA describes permissible exposure limits for an eight-hour time-weighted average, a ceiling and conditions
ACGIH	TLV	Worker exposure	These are threshold limit values (TLV) for an eight-hour workday on a time weighted average (TWA), short-term exposure limit for 15 minutes (STEL), and a ceiling (C) not to be exceeded
DOE - SCAPA	TEEL	DOE workers and public	The Temporary Emergency Exposure Limit is a three-tier guideline developed by DOE SCAPA for use by DOE and DOE contractors when AEGL or ERPG values were not available

Toxic fluids

The information in API 521, and thus in this analysis, is based on the characteristics of hydrocarbon vapors. Thus, when effluent streams deviate from this assumption, the system designer is cautioned to use good engineering judgement.

In addition to the previously identified considerations, evaluation of toxic fluid release should consider the followings analysis:

Vapor-phase releases. Releasing toxic vapor to atmosphere might be safe if the concentration of the toxic component in the release decreases to below acceptable threshold before the effluent comes in contact with personnel.

Liquid-phase releases. Releasing toxic, volatile liquids directly to the atmosphere should be avoided. The discharge of liquids that are nonvolatile (such as caustic) may be acceptable. However, acceptance criteria for these releases is out of the scope of this article.

Concentration of toxics in release streams. The diffusion and dilution effects apply to all constituents of the effluent. The guidance in API STD 521 7th edition §5.8 indicates that for typical hydrocarbon streams, the concentration might be diluted to below 5.0 vol.% for methane and 1.2 vol.% for hexane on a volume basis before losing the jet momentum. Therefore, if the toxic fluid can be assumed to have similar characteristics to light hydrocarbon, the concentration of toxic components may be diluted anywhere from 1/20 to 1/80 of the original concentration, due to the effects of jet mixing.

Hence, Equation (6) may be used to estimate the maximum concen-

tration of a toxic compound in an effluent stream that meets all the criteria in the list given in the "semi-quantitative analysis" section. If there is the potential for personnel in the immediate vicinity of the area of release plume (while it is still a jet), detailed dispersion modeling may be required.

$$C_{Limit} > \left(\frac{C_{Effluent}}{20}\right) \qquad \textbf{(6)}$$

Where:

C_{Limit} = the highest concentration that meets the risk acceptance for the toxic material, ppm (see Table 2)

$C_{Effluent}$ = the concentration of the toxic material in the effluent stream, ppm

Determining an acceptable lower concentration (C_{Limit}) can be difficult, but there are a variety of sources that offer guidance (see Table 2). The list in Table 2 is only provided for guidance. It is the responsibility of the system designer to ensure that all regulatory and site requirements for releases are met.

In summary, if systems meet the qualitative criteria listed and if the concentration limits satisfy Equation (6), the maximum toxic concentration to which workers may be exposed should be below the concentration that meets the risk-acceptance criteria. For example, if the relief-device toxic vapor release has a H_2S concentration of 2,000 ppm (or less), then the peak exposure will be below the IDLH (immediate danger to life and health) concentration of 100 ppm for locations where personnel are present. Corporate or regulatory requirements may be different than this example for H_2S.

This screening method has limited applicability for streams that contain high concentrations of toxic materials or for facilities that handle extremely toxic chemicals. Users are cautioned if using this screening method for materials that do not have characteristics similar to light hydrocarbons, because the jet-mixing effect of those streams might be different. For those systems, detailed dispersion modeling might be needed.

Concluding remarks

The methods presented here are simplified and can be readily used by system designers to screen atmospheric relief-device installations to meet the "safe location" criteria as presented in API STD 521. Following the methods outlined in this article, a system designer should be able to document each of the following questions:

- Do these relief valves discharge to a "safe location"?
- Can we show that the discharge location meets good engineering practices?
- Which relief-device systems require additional analysis (dispersion modeling)?

For each atmospheric discharge, if the provided systematic decision-making process is followed and documented, atmospheric discharges can be shown to vent to a "safe location," as required by good engineering practice. Detailed dispersion modeling was performed to validate the results of the simplified equations presented here. While there are always rare circumstances that can occur, under the most common conditions that hydrocarbon streams are processed, the methods discussed here are conservative and can be used to screen atmospheric relief-device installations. ■

Edited by Scott Jenkins

Disclaimers

All information presented in this article is meant to be used by a qualified and experienced engineer or relief system designer. The content of this article is general in nature and based on the guidance provided in API STD 521. It is up to the end user to verify the safety and/or legality of any installations. With any predictive model, there may be variations between the results predicted and the results that occur from any given incident. For energetic or extremely toxic substances, or those where the concentrations predicted are close to the acceptable limits and risks, additional analysis should be performed. The user is cautioned to design a system that has a safety margin that allows for the inherent errors in this type of estimation. As with other aspects of these evaluations, good engineering judgment and knowledge of the specific installations must be considered.

This article is offered for general informational purposes only. Readers should consult with a qualified profession regarding their specific projects or work. The authors disclaim any and all liability arising from or concerning the analysis contained in this article.

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Authors

Dustin Smith is a co-founder and principal consultant at Smith & Burgess (7600 W. Tidwell Rd., suite 600, Houston, TX 77040; Email: info@smithburgess.com; Phone: 1-713-802-2647; www.smithburgess.com) a process safety consulting firm headquartered in Houston. He has extensive experience helping facilities that process highly hazardous chemicals maintain compliance with the OSHA process safety management (PSM) standard. Smith has over 25 years of experience in relief and flare system designs and PSM compliance. Smith received a B.S.Ch.E. from Texas A&M University. Smith is a licensed engineer in the state of Texas.

John Burgess is a co-founder and principal consultant Smith & Burgess (same address as above). He has extensive experience providing assistance to facilities that process highly hazardous chemicals in maintaining compliance with the OSHA process safety management (PSM) standard. Burgess has over 25 years of experience in relief and flare system designs and PSM compliance. Burgess received a B.S.Ch.E. degree from Texas Tech University and a M.S. from University of Missouri. Burgess is a licensed engineer in the state of Texas.

Thuc Ngo is a lead consultant at Smith & Burgess (same address as above). She has over 10 years of experience working on over 100 projects in relief & flare system designs. She received B.S.Ch.E. and M.S.Ch.E. degrees from the University of Houston. Ngo is a licensed engineer in the state of Texas.

Materials of Construction: Stainless Steel Versus Nickel Alloys

Nickel alloys have long been the default choice for demanding applications in the chemical process industries (CPI). A new grade of stainless steel offers an alternative

Rodrigo Signorelli and Jan Li
Outokumpu

IN BRIEF

STAINLESS STEEL BACKGROUND
THE PASSIVE LAYER IS THE KEY
CATEGORIES OF STAINLESS STEEL
RANKING STAINLESS STEELS
COMPARING S32654 TO OTHER ALLOYS
STAINLESS STEEL VERSUS TITANIUM
PROVEN IN THE FIELD

Demanding chemical engineering applications, such as plate heat exchangers (PHEs; Figure 1), tubing, pipes and pumps, call for materials that offer exceptional performance in extremely corrosive environments. That's why many design engineers regard nickel alloys as their "go-to" choice. A popular selection is Alloy 625 (UNS N06625). This is a nickel-chromium-molybdenum superalloy that possesses both high strength and resistance to elevated temperatures. The alloy is particularly resistant to pitting and crevice corrosion as well as to severely corrosive environments.

However, for all the performance benefits that nickel alloys bring, there is also a significant downside. Because as well as being expensive, nickel is subject to extremely volatile pricing. For example, current geopolitical concerns have seen nickel prices fluctuate by a factor of around three in less than a year. The strategic importance of nickel for the battery sector is also likely to act as a further driver for prices over the next two decades.

These factors are driving design engineers to broaden their scope to consider alternatives to nickel alloys. A leading contender is ASTM UNS S32654 (EN 1.4652), an austenitic stainless steel grade known as the most corrosion-resistant in the world.

By switching to S32654, designers can take advantage of a stainless steel that offers comparable performance to Alloy 625, with a typical cost reduction of 30 to 40%. It also comes with the advantage of much more stable pricing.

Stainless steel background

In 1913. the English metallurgist Harry Brearley discovered that the addition of chromium in combination with a relatively low carbon content dramatically increased the corrosion resistance of steel. He called his 12.8% chromium (Cr) and 0.24 % carbon (C) containing martensitic alloy "rust-less steel" and introduced it to the cutlery industry in his hometown Sheffield, U.K.

At the same time, the company Krupp in Germany discovered that steels with high Cr or Cr-Ni could be stored for months in humid and aggressive environments without rusting. This revolutionary material had hygienic-surface properties and was able to withstand aggressive foodstuff, such as vinegar or lemon juice. Stainless steel quickly became the preferred material not only for cutlery and tableware but also in the food-processing industry, because of its hygienic-surface properties.

Today, there are hundreds of different types of stainless steels available for all kinds of applications.

The passive layer is the key

Stainless steels are not fundamentally noble materials in the same way as gold or platinum, which are more or less inert to most environments. Instead, stainless steels de-

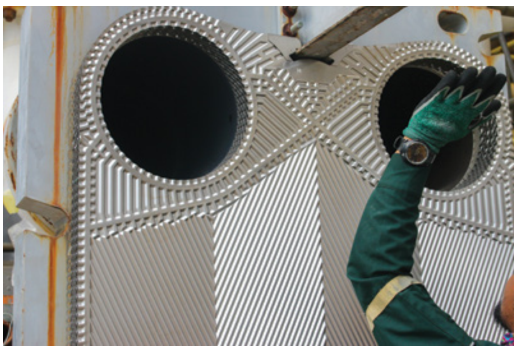

FIGURE 1. For harsh, corrosive applications, selecting the best material of construction is important for equipment, such as heat exchanger plates

rive their corrosion resistance from a thin, invisible and insoluble layer of chromium and iron oxides and hydroxides, commonly called the passive film, or passive layer. Even though the passive layer is only a few nanometers in thickness, this passive layer effectively keeps the metal beneath isolated from its surroundings and electrochemical reactions causing corrosion are effectively slowed down. The passive layer reduces the corrosion rate to only a fraction of what it would be without it. Other metals, such as chromium, aluminum and titanium, also show passivity, and it is the ability of chromium to passivate that is utilized in stainless steels.

The passive layer on stainless steels forms spontaneously in environments containing enough oxidants. Moreover, if the metal beneath the passive layer is exposed by mechanical damage, such as scratches, it spontaneously repassivates. The oxygen content of air, and also of most aqueous solutions, is enough for both the creation and maintenance of the passive layer of stainless steels.

However, there are environments that cause permanent breakdown of the passive layer. Under circumstances where the passive layer cannot be rebuilt, corrosion occurs on the unprotected surface.

For the passive layer to break down in its entirety, stainless steels need to be exposed under strongly reducing conditions. More commonly, the passive film is attacked locally while the rest of the surface remains intact, causing various types of localized corrosion. The situation that then occurs with an unfavorable anode-to-cathode area ratio can lead to very rapid propagation once corrosion has initiated.

This means that the use of stainless steel in a specific environment or application is usually an either/or situation. That is, the material is either passive or tends to corrode rapidly, with little scope for intermediate conditions. This can be compared to carbon steel, where a corrosion allowance is commonly used and where gradual, uniform corrosion is expected. If the passive layer is maintained, stainless steel can almost last forever.

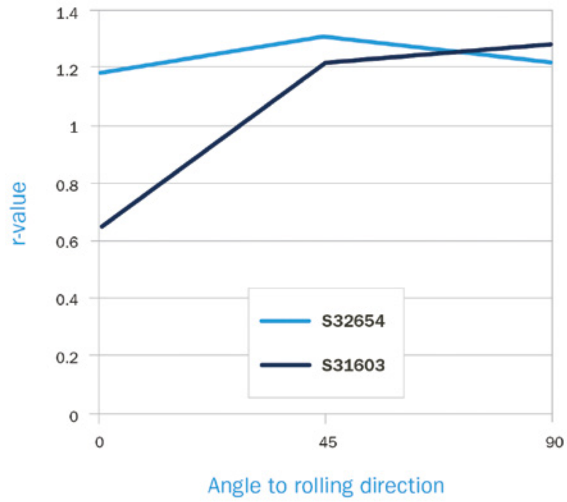

FIGURE 2. USN S32654 has more favorable r values in all directions, which makes it suitable for pressed components, such as sheets for PHEs

Categories of stainless steel

Traditionally, stainless steels are categorized according to their microstructure into ferritic, austenitic, duplex and martensitic and precipitation-hardening stainless steels.

Ferritic stainless steels. Ferritic stainless steels, also known as Cr-steels, are alloyed with chromium (Cr) but with either a small amount of nickel (Ni) or no nickel at all. Molybdenum (Mb) is added to some steels to improve corrosion resistance, while alloying with niobium (Nb) and/or titanium (Ti) improves weldability.

These steels are magnetic and have high resistance to stress corrosion cracking (SCC) but moderate resistance to uniform, pitting and crevice corrosion.

High-temperature ferritic stainless steels for use at temperatures between 800 and 1,150°C are also available.

Austenitic stainless steels. Austenitic stainless steels are the largest group of stainless steels and can be divided into five subcategories:

- Cr-Ni steels
- Cr-Mn steels
- Cr-Ni-Mo steels
- High-performance austenitic steels
- High-temperature austenitic steels

Austenitic stainless steels are nonmagnetic in the solution-annealed condition. They have moderate to excellent corrosion resistance, depending on the steel.

Cr-Ni steels (18-8). These "general purpose" stainless steels are mainly alloyed with chromium and nickel but with no molybdenum. They are sometimes referred to as 18–8 type stainless steels in reference to their approximate chromium and nickel content. In the past, titanium and niobium stabilization was used to improve their resistance to intergranular corrosion, but this is not necessary for modern low-carbon Cr-Ni steels. They have moderate resistance to

TABLE 1. COST COMPARISON

Grade	Price indication*
316L	Base (1)
UNS S31254	3–4
UNS S32654	5–8
Alloy 625	9–12

*Note: Illustrative example. UNS S32654 is considerably less expensive than Alloy 625 according to historical market-price-level indications, mainly influenced by fluctuations in raw material costs.

TABLE 2. ALLOYING ELEMENTS, % COMPOSITION

Steel grade	EN	UNS	C	Cr	Ni	Mo	N	Other
Ultra 654 SMO	**1.4652**	**S32654**	**0.010**	**24**	**22**	**7.3**	**0.5**	**3.5 Mn, Cu**
Ultra 254 SMO	1.4547	S31254	0.010	20	18	6.1	0.02	Cu
Alloy 31	1.4562	N08031	0.015	27	31	6.5	0.2	2 Mn, Cu
Alloy 625	**2.4856**	**N06625**	**0.030**	**22**	**Min. 58**	**9.0**	**–**	**3.5 Nb + Ta**
Alloy 22	2.4602	N06022	0.010	21	Min. 50	13	–	3 W, 2.5 Co
Alloy C-276	2.4819	N10276	0.010	16	Min 52	16	–	3.5 W, 2.5 Co
Alloy 59	2.4605	N06059	0.010	23	Min. 60	16	–	0.1–0.4 Al

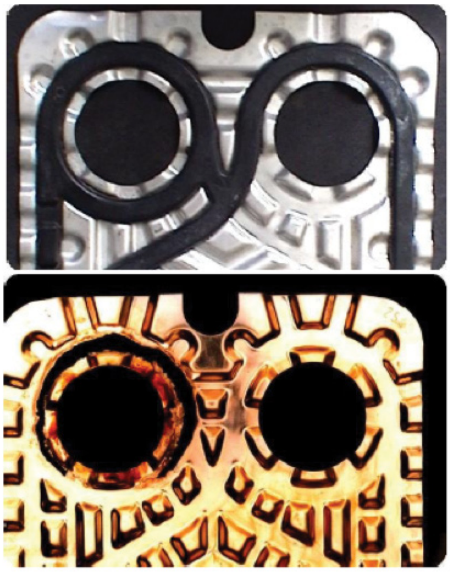

FIGURE 3. Sea water testing of PHE plates of a plate-and-frame heat exchanger. The upper image is 654 SMO and lower image is 254 SMO under the same conditions and time frame

uniform, pitting, and crevice corrosion, but rather poor resistance to stress corrosion cracking.

Cr-Mn steels (200-series). These steels are also referred to as "200-series" steels in reference to the AISI/ASTM nomenclature. Their nickel content is decreased and the austenitic microstructure is maintained by replacing some of the nickel with manganese and nitrogen. They have moderate resistance to uniform, pitting and crevice corrosion, but rather poor resistance to stress corrosion cracking.

Cr-Ni-Mo steels. These are another type of "general purpose" stainless steels. They are alloyed with chromium and nickel but have increased corrosion resistance because of their molybdenum content. They are sometimes referred to as "acid-proof" stainless steels. In the past, titanium and niobium stabilization was used to improve resistance to intergranular corrosion, but this is not necessary for modern low carbon Cr-Ni-Mo steels. They have good resistance to uniform, pitting, and crevice corrosion, but rather poor resistance to stress corrosion cracking.

High performance austenitic steels. These steels were developed for use in highly demanding environments and have high chromium, nickel and molybdenum content. Many are also alloyed with nitrogen to further increase corrosion resistance and mechanical strength. Some of these steels are alloyed with copper to increase the resistance to certain acids. They have high resistance to uniform, pitting, crevice and stress corrosion cracking.

Within this category, superaustenitic stainless steels are normally used where greater resistance to corrosion, especially protection from chloride pitting and crevice corrosion, is needed. They are defined as austenitic, iron-based alloys that have pitting resistance equivalent (PRE) greater than 40, such as UNS S32654, that is also known as a 7Mo superaustenitic grade.

High-temperature austenitic steels. These steels, developed for use at temperatures exceeding 550°C, have high chromium and nickel content, but contain no molybdenum. They have good oxidation and creep resistance.

Duplex stainless steels. Duplex stainless steels have a ferritic-austenitic microstructure, with a phase balance of approximately 50% ferrite and 50% austenite. They are magnetic due to their ferrite content. Duplex steels combine many of the beneficial properties of ferritic and austenitic stainless steels. Compared with austenitics, they typically have high chromium content but rather low nickel content. Molybdenum and nitrogen are added to improve corrosion resistance and balance the microstructure. Nitrogen also increases the mechanical strength.

Duplex steels should only be used at temperatures between –40 and 250°C, because they become brittle outside this temperature range. They have high resistance to stress-corrosion cracking, while resistance to uniform, pitting and crevice corrosion varies between moderate and high, depending on the steel.

Martensitic and precipitation hardening stainless steels. Martensitic stainless steels is the smallest group of stainless steels. They contain chromium and either no or

TABLE 3. PHYSICAL PROPERTIES

Steel grade	Density, kg/dm^3	Thermal conductivity at 20°C, W/m·K	Electrical resistivity at 20°C, Ohms. mm^2/m	Modulus of elasticity at 20°C, GPa	Coefficient of thermal expansion, 10^{-6}/K
S32654	**8.0**	**11**	**0.78**	**190**	**15**
S31254	8.0	14	0.85	195	16.5
N08031	8.1	11.7	1.03	198	14.3
Alloy 625	**8.5**	**9.8**	**1.25**	**209**	**12.5**
N06022	8.7	9.4	1.14	206	12.4
N10276	8.9	10.6	1.25	208	11.7
N06059	8.6	10.4	1.26	210	11.9

only small additions of nickel and molybdenum. Adding nickel and reducing the carbon content can improve their rather poor weldability. Martensitics are magnetic and hardenable. The corrosion resistance of these steels is generally lower than the other stainless-steel families and they are used mainly when high hardness is a key requirement.

Ranking stainless steels

The PRE number is used to rank different stainless steels regarding their resistance to pitting corrosion, taking into account the effect of the most important alloying elements. PRE is calculated by the following formula:

$$PRE = \%Cr + 3.3 \times \%Mo + 16 \times \%N \quad (1)$$

The higher the PRE, the higher the resistance to pitting.

Comparing S32654 to other alloys

For very demanding corrosion resistance, stainless-steel S32654 features alloying elements that are very important for resistance to localized corrosion, such as Cr, Mo and especially nitrogen (N). This gives the grade resistance to pitting and crevice corrosion that will always outperform Alloy 625. Also, S32654 is stronger than standard austenitic stainless steels and nickel alloys, while having the formability of a conventional austenitic grade.

Cost. In terms of pricing, S32654 sits between 316L, regarded as the starting point for high-performance stainless steels, and Alloy 625. Using 316L as the baseline, as shown in Table 1, S32654 is clearly considerably less expensive than Alloy 625 while offering comparable performance.

A key benefit of S32654 is that it offers better price stability than Alloy 625. This is because it has a lower percentage composition of nickel and molybdenum that are particularly subject to variations in commodity pricing (see Table 2).

Density. As seen in Table 3, S32654 has a lower density than Alloy 625 — 8.0 compared with 8.5 kg/dm^3. Although that difference may appear small, it could be crucial to the project costing. For example, the lower density might result in a typical reduction of 6% in tonnage when buying large amounts of material, such as for a long pipeline. Both stainless steel and nickel alloys are purchased by the ton, so the potential weight saving translates directly into cost savings.

Furthermore, the lower density of S32654 also makes the whole system lighter. This could enable easier handling and installation, which might be especially important for subsea and offshore structures.

Mechanical properties. The mechanical properties of some typical corrosion-resistant alloys are shown in Table 4, namely the proof stress (Rp), tensile strength (Rm) and elongation (A50). The conclusion is that S32654 is stronger than Alloy 625, enabling components to be manufactured using thinner gauges, saving on both weight and cost.

Fabrication. An important indication of a material with good drawing properties is its "r-value", otherwise known as the plastic strain ratio. The higher the r-value, the better. Furthermore, measuring the r-value in different tensile directions shows how a sheet material will withstand thinning during forming.

Figure 2 confirms that S32654 has excellent r-values in different directions, and much better than 316L. That makes it ideally suited for pressed components such as sheets for PHEs. The material also has similar deformation hardening rates to other austenitic grades.

S32654 is also suitable for hot working. To maintain its mechanical properties, it should be quenched at a temperature of between 1,100 to 1,200°C to remove intermetallic phases formed during the hot working operation. For welding, S32654 has good weldability in common processes.

In common with all austenitic stainless steels, S32654 work-hardens quickly. This, together with its high toughness, means that it can be perceived as challenging from a machining perspective in operations such as turning, milling and drilling. However, with

TABLE 4. MECHANICAL PROPERTIES

Steel grade	$R_{p0.2}$	R_m	A_{50}
S32654	**≥ 430**	**≥ 750**	**≥ 40**
S31254	≥ 300	≥ 650	≥ 40
N08031	≥ 276	≥ 650	≥ 40
Alloy 625	**≥ 330**	**≥ 730**	**≥ 35**
N06022	≥ 310	≥ 690	≥ 45
N10276	≥ 283	≥ 690	≥ 40
N06059	≥ 310	≥ 690	≥ 45

TABLE 5. CPT AND CCT TESTING

Steel grade	ASTM G48 E and F[1]		Green death[2]
	CPT, °C	CCT, °C	CPT, °C
S32654	**> BP[3]**	**60**	**90**
S31254	65	35	60
Alloy 625	**90**	**25**	**75**
N06022	> 100	60	–
N10276	> BP	50	100

1. ASTM G48: 6% $FeCl_3$ + 1% HCl; 24 h
2. Green Death: 11.4% H_2SO_4 + 1.2% HCl + 1% $FeCl_3$ + 1% $CuCl_2$; 24 h
3. BP = boiling point

TABLE 6. CPT TESTING TO ASTM G150	
Steel grade	**CPT, °C**
S32654	**>90**
S31254	85
N08031	> 90
Alloy 625	**> 90**
N06022	> 90
N10276	> 90

the right choice of tools, tool settings and cutting speeds, it can be machined successfully.

Corrosion resistance. S32654 offers very good resistance to uniform corrosion, exceptionally good resistance to pitting and crevice corrosion with a PRE number of 56 and very good resistance to stress corrosion cracking (SCC). Laboratory testing shows that S32654 has a higher corrosion resistance in chloride environments than Alloy 625, and similar performance to C-276, a nickel-molybdenum-chromium alloy that exhibits excellent corrosion resistance in a variety of harsh environments and media.

The relative resistance to pitting and crevice corrosion of materials can be illustrated in different ways by using the critical pitting temperature (CPT) and crevice corrosion temperature (CCT) as determined by the technical standards: ASTM G48E (CPT), ASTM G48F (CCT) and ASTM G150 (CPT).

Table 5 illustrates the results of CPT and CCT testing on dry ground surfaces prepared with 120 grit. Table 6 shows the results of CPT testing to ASTM G150 on wet ground surfaces prepared with 320 grit.

Stainless steel vs. Ti

It is not only nickel alloys that might be usefully substituted by S32654. It can also offer an interesting cost-effective alternative to titanium in some applications, especially heat exchangers. In fact, it will outperform titanium in any application exposed to fluoride ions, as this is harmful to titanium.

Proven in the field

The capabilities of S32654 have been tested in a wide variety of applications. A few of these are high-

lighted here.

Plate heat exchanger. An important field test was carried out on PHEs manufactured from three materials. These were exposed to seawater with a North Sea salinity of 3.3–3.6% (see Figure 3). Testing was carried out at 45, 50, 60 and 70°C with 2 parts per million (ppm) continuous chlorination over three months.

The first sample was S31254, a 6% molybdenum and nitrogen-alloyed austenitic stainless steel with extremely high resistance to both uniform and localized corrosion. It was developed especially for oil-and-gas offshore platforms and the pulp-and-paper industry, yet at 45°C it showed crevice corrosion. The nickel alloy C-276 suffered shallow crevice corrosion and transpassive corrosion. In contrast, S32654 was resistant to crevice corrosion at 70°C.

Condenser tubing. The first installation of S32654 took place in the 1990s, when close to 94,000 m of tubes (O.D. 24 × 0.7 × 7.815 mm) were used to replace titanium condenser tubes at Forsmark 1 and 2 nuclear power plants in Sweden.

This was followed by 56,000 m of tubing at Ringhals, Sweden and 58,000 m at TVO in Finland. In total these installations included more than 200 km of 654 SMO condenser tubes.

Pharmaceutical plant. Vent systems in pharmaceutical plants can be exposed to very aggressive gases, such as hydrogen chloride. S32654 was installed in the pilot plant of a Swedish pharmaceuticals company.

A variety of active substances have been tested in this plant including chloride-containing solutions with pH values ranging from 0 to 14, with successful results.

Fluegas desulfurization. S32654 has good potential for fluegas desulfurization plant. For example, in 2017, Babcock Noells specified it for plates in absorption towers. It can also be used for the scrubber inlets of marine exhaust gas. As the entry point for hot exhaust gas, this is a particularly demanding application.

Traditionally, Alloy 31 has been the material of choice for this type of project. It is an iron-nickel-chromium-molybdenum alloy with added nitrogen. This fills the gap between special alloyed austenitic stainless steels and nickel alloys. However, S32654 has a higher mechanical strength than Alloy 31. If the design of the inlet enables this higher strength to be utilized then it could offer weight savings between 15 to 25%. Furthermore, the lower nickel content of S32654 also makes it cost-effective and more stable in price.

Waste incineration. Fluegas from municipal waste incineration plants can contain hydrogen chloride and hydrogen fluoride due to the presence of plastics, such as polyvinylchloride (PVC) and polytetrafluoroethylene (PTFE) in the garbage.

In 1995, a scrubber made of S32654 was installed at a municipal-waste incineration plant in Zeebrugge, Belgium. Service conditions in the most aggressive area included exposure to 35,000 ppm of chlorides at pH 0.5 and a temperature of 80°C. The first inspection was made at a shutdown after almost 15 months of continuous service. The scrubber was found to be in excellent condition.

Solvent recovery. When recovering solvents from emitting air in certain processes, solvent molecules are trapped in active carbon filters. After being saturated, the filters are back-flushed with steam at 100–120°C and the steam condensate solvent mixture is later cooled and separated.

Chlorides or hydrochloric acid in the process can cause corrosion of filter housings made of stainless steel. Severe corrosion on 316L has been reported after very short periods of service when the solvent was methylene chloride.

The first industrial application of S32654 for this process was for two active carbon filters at a facility in Plymouth, England in 1992.

Pulp bleaching. Bleaching of pulp in the paper industry exposes the equipment to strongly oxidizing and chloride-containing solutions, sometimes at low pH levels. Comparing the material options, conventional stainless-steel grades are susceptible to pitting and crevice corrosion in bleaching processes based on chlorine/chlorine dioxide, but are resistant to bleaching based on peroxide. Titanium is resistant to chlorine/chlorine dioxide, but can be susceptible to uniform corrosion in peroxide solutions. Nickel-based alloys are resistant to peroxide but can suffer transpassive uniform corrosion in chlorine dioxide solutions.

Being an iron-based alloy, S32654 is resistant to uniform corrosion in peroxide and to transpassive corrosion in chlorine dioxide. It also has very high resistance to pitting and crevice corrosion. This combination makes it an ideal material for bleach plant components.

One example where 32654 has been used is a nozzle in a D-stage bleach tower at a Swedish pulp plant, replacing 316L, which lasted only 4 weeks. The environment contains 3,000 ppm of chlorine dioxide, the pH is 3–3.5 and the temperature is 70°C. It has also been used for D-stage filter washers in plants in Canada, the U.S. and Indonesia. ■

Edited by Gerald Ondrey

Authors

Rodrigo Signorelli is a technical manager at Outokumpu, Americas (Rua Bandeira Paulista 600, An 7 Cj 71, 04532-001, Itaim Bibi - São Paulo, Brazil; Phone: +55-1124-951-924; Email: sales.brazil@outokumpu.com). Signorelli is a materials engineer with a wealth of experience in applying stainless steel in industrial markets. He provides technical advice and support to customers across the world and has played a key role in launching new stainless-steel grades in his career. He holds an MBA degree from Fundacao de Administracao and a degree in materials engineering from Universidade de Sao Paulo.

Jan Li is a technical manager at Outokumpu, Asia (No. 288, Chenfeng Road, Yushan Town, Kunshan, Jiangsu Province, 215300 China; Phone: +86-512-5012-0358; Email: sales.china@outokumpu.com). Based in Beijing, Li has is a qualified metallurgist with a masters degree in the strength and fracture of welded structures. He has worked with Outokumpu for over 20 years and has extensive experience in the marketing development and sales of stainless steels, welding consumables and industrial equipment. Li holds master's and bachelor's degrees from Tianjin University. He is also a certified senior welding engineer from the Metallurgy Ministry of China.

More Specification Tips to Maximize Heat Transfer

Presented here are practical points to help in the selection of plate-and-frame and air-cooled heat exchangers

John Boyer and Jim Klimek
Xylem Inc.

With a wider variety of heat exchangers to choose from than ever before, there are a number of variables to be considered when assessing options.

As energy-intensive industries increasingly look for ways to improve efficiency, choosing the right heat exchanger to fit the needs of specific applications and systems is critical.

In the second part of this two-part series, we look at specification tips to maximize heat transfer in plate-and-frame and air-cooled style heat exchangers in order to boost heat-exchanger performance and increase efficiency. (For part 1, which covered shell-and-tube heat exchangers, see *Chem. Eng.* February 2022, pp. 42–44).

Plate-and-frame exchangers

The plate-and-frame heat exchanger has emerged as a viable alternative to shell-and-tube exchangers for many applications. Such units are composed of a series of plates, mounted in a frame and bolted together. Space between adjacent plates form flow channels, and the system is arranged so that hot and cold fluids enter and exit through ports at the four corners (Figures 1 and 2).

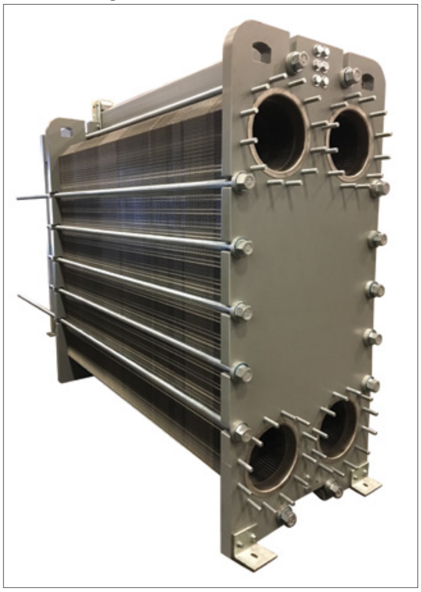

FIGURE 1. When the plates of a plate-and-frame exchanger are assembled, the holes in the corners form a continuous channel. Alternating gasket patterns direct the hot and cold fluids into alternating passes. Heat transfer then takes place across the plates

Within the exchanger, an alternating gasket arrangement diverts the hot and cold fluids from each inlet into an alternating sequence of flow channels. In this arrangement, each cell of heat-transfer media is separated by a thin metal wall, allowing heat to transfer easily from one media to the other.

A corrugated chevron or herringbone pattern is pressed into each plate to give the exchanger strength and rigidity, to extend the effective surface area of plates and to increase turbulence in the flow channels, which combined, boost heat transfer (Figure 2).

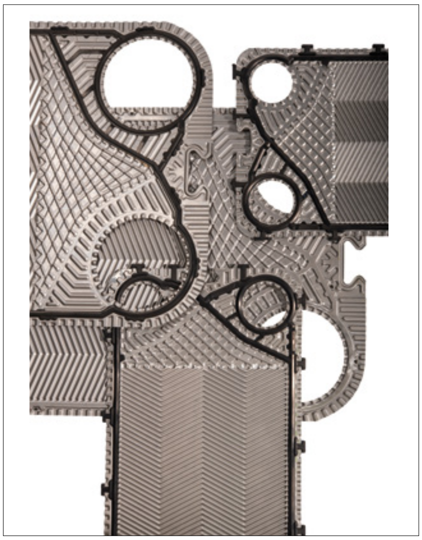

FIGURE 2. A corrugated chevron or herringbone pattern is pressed into each plate to give the exchanger strength and rigidity, to extend the effective surface area of plates and to increase turbulence in the flow channels, which combined, boost heat transfer

The plate and frame's highly efficient countercurrent flow typically yields heat-transfer coefficients three to five times greater than other types of exchangers. As a result, a more-compact design is possible.

Depending on the applications, plate selection is optimized to yield the fewest total number of channel plates. Because the plates can be easily removed, service and maintenance costs are typically lower than that of shell-and-tube exchangers.

Although the plate-and-frame heat exchanger can be used in a broad range of applications, the following selection criteria may be used as a guideline:

- Maximum design or working pressure is limited to 450 psi
- Temperature limits and fluids must be compatible with gasket materials, typically limited to 300°F
- Plate materials must be compatible with process media
- The narrow passageways in the plate and frame can result in high pressure drops, making the exchanger incompatible with low-pressure, high-volume gas applications
- Rapid fluctuations in steam pressures and temperatures can be detrimental to gasket life. For this reason, applications that use steam favor shell-and-tube exchangers
- In applications where process media contain particulate matter, careful consideration should be given to the free channel space between adjacent plates. Maximum weight percentage of 20% solids with particle size not exceeding 50% of the free channel space are typical limits
- The plate-and-frame design is best suited for applications with a large temperature cross or small temperature approach. A temperature approach of 2°F is often achievable

Early designs of plate-and-frame heat exchangers used glue to attach gaskets to plates. The glue was often applied unevenly, greatly increasing the chance of process fluid

FIGURE 3. In tube-and-fin air-cooled exchangers, a motor-and-fan assembly forces ambient air over a series of tubes, to cool or condense the process fluids carried within. Tapered fins are typically added to the tubes to extend the surface area and maximize heat transfer

leaking through the gasket groove of the plate and either contaminating other fluids or escaping to the atmosphere. Additionally, the replacement of glued gaskets can be challenging.

Many plate-and-frame heat exchangers are now offered with a glueless gasket system. The plate construction uses clips and studs to secure gaskets to the plates. This method eliminates irregularities in the gasket groove and results in better sealing of the plate pack.

The glueless system also cuts service and maintenance costs, since the plates can be cleaned or regasketed without removing them from the frame.

Double-wall plate exchangers. Double-wall plate heat exchangers offer even greater protection against gasket failure. In traditional plate-and-frame exchangers, the process fluids are contained by gaskets and thin, metal plates. In double-wall exchangers, two plates are welded together at the port holes to form one assembly, with an air space between the plates. In the event that one of the two plates should develop a hole or perforation, the fluid will leak into the space between the two plates and then to the atmosphere, instead of entering an adjacent fluid passageway and contaminating the other process stream.

Typical applications include:
- Domestic water heaters
- Hydraulic oil cooling
- Any service where cross contamination of process fluids cannot be tolerated

Welded-plate exchangers. In this design, the field gasket that normally contains the process fluid is replaced by a welded joint, greatly minimizing the amount of fluid exposed to the gasket material and making this design suitable for hazardous or aggressive fluids.

The welded plates form a closed compartment or "cassette." Similar to gasketed designs, alternating flow channels are created to divert the flow of hot and cold fluids into adjacent channels. Aggressive fluids pass from one cassette to the next through an elastomer or Teflon ring gasket, while non-aggressive fluids are contained by standard elastomer gaskets. The use of welded joints can reduce total gasket area by 90% on the aggressive-fluid side.

Typical applications include exchangers handling the following:
- Vaporizing and condensing refrigerants
- Corrosive solvents
- Amine solutions

Wide-gap plate exchangers. Compared with traditional plate-and-frame exchangers, this design relies on a plate pattern with significantly larger free channel spacing, which provides improved resistance to clogging. The plates are designed with few, if any, contact points between adjacent plates to allow fibers or solids to pass. Some styles of this exchanger use wide-gap plates on the process side and conventional chevron patterns on the coolant side, to enhance heat transfer.

Typical applications include exchangers handling the following:
- White water in pulp-and-paper operations
- Slurries

Brazed-plate exchangers. In this design, the elastomer gaskets found in most plate-and-frame exchangers are replaced with a brazed joint, which greatly reduces the possibility of leakage. The corrugated heat-transfer plates, which are typically available in stainless steel, are brazed together using either a copper or nickel brazing material.

The brazed-plate exchangers are typically rated to 435 psi, but could be rated in excess of 2,000 psi. Temperature ratings vary from 450°F for copper brazing to 750°F for nickel brazing. As with other plate-and-frame exchangers, high

FIGURE 4. This design also utilizes a motor-and-fan assembly, but instead of tubes, corrugated plates and fins are added to a brazed-composite core, to create alternating air and fluid passages

heat-transfer rates translate to compact designs. Because of the rigid brazed alloy construction, temperature differential between the two fluids should be considered and is typically limited to 200°F.

Typical applications include:

- Units that vaporize and condense refrigerants
- Oil heating or cooling
- Applications requiring high alloys
- Heat-recovery applications
- Brine exchangers
- Applications involving liquid ammonia, chlorine solutions, alcohols or acids

Tube and continuous-fin air-cooled exchangers. In the tube-and-fin air-cooled exchanger, a motor and fan assembly forces ambient air over a series of tubes, to cool or condense the process fluids carried within. The tubes are typically assembled in a coiled configuration (Figure 3).

Air is readily available, but it is a relatively poor heat-transfer medium. Use of air-cooled heat exchangers can greatly help eliminate the use of valuable cooling-water supplies. To increase the heat transfer rates of the system, the tubes in air-cooled exchangers are typically given fins, which extend the surface area and increase heat transfer.

The diameter and materials specified for the tubes and fins depend on system requirements. The fins are commonly made from aluminum or copper but may be fabricated of stainless or carbon steel. Tubes are generally copper, but can be made from almost any material, and they typically range in size from 3/8- to 1-in. outer diameter.

Typical applications include:

- Oil cooling
- Compressed-air cooling
- Water or glycol cooling
- Heating and air conditioning
- Process heating and cooling
- Air-cooled process equipment
- Energy and solvent recovery
- Combustion air preheating
- Fluegas reheating

Aluminum-bar and plate air-cooled exchangers. Similar to the tube and continuous-fin design, this design also utilizes a motor-and-fan assembly, but instead of tubes, corrugated plates and fins are added to a brazed-composite core, to create alternating air and fluid passages (Figure 4). This compact, lightweight design is considered the most cost-effective air-cooled unit available. Turbulence created in the fluid channels boosts efficiency and reduces required size and surface area. Typical applications include:

- Cooling lubrication oil for power equipment
- Cooling fluids for hydraulic equipment
- Cooling gearbox fluids

Concluding remarks

Clearly, for most applications and heat exchanger types, there are a multitude of choices and options available. These guidelines should provide a basis for comparison. No matter what configuration is ultimately implemented, the emphasis on clean, efficient heat recovery ensures that the heat exchanger will remain one of the most critical components in the manufacturing process. ■

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Authors

John Boyer is the Heat Transfer Commercial Team manager at Xylem Inc. (1 International Drive, Rye Brook, N.Y. 10573; Phone: 716-303-6179; Email: john.boyer@xylem.com). He has additionally held roles in application engineering, product/market management, engineering and general management. Boyer holds a B.S.Ch.E. from the State University of New York at Buffalo and Six Sigma Green Belt Certification, Lean, from the University of Michigan College of Engineering.

Jim Klimek is the Heat Transfer Global Product manager at Xylem Inc. (Same address as above; Phone: 716-862-4118; Email: jim.klimek@xylem.com). He has additionally held roles in application engineering and product and application-engineering management. He holds a B.S.Ch.E. from the State University of New York at Buffalo.

One-stage Filtration for Silicone Production

Presented here is a fast and flexible solution that removes solids, traces of water and gel in a single operation, therefore significantly reducing the time it takes to perform the process during silicone production

Reliable silicone manufacturing operations depend on a complex network of process technologies, including, among other things, the removal of solids as well as traces of water and gels from the intermediate silicone product. Traditionally, this activity has been a two-stage operation. However, there is a single-stage filtration technique that combines the removal of solids, water and gels that can enable a manufacturer of silicone products to streamline its production activities and enhance operational efficiency.

Silicone products

Specialty silicones are used in a broad range of industries. From adhesives to aerospace, textiles and transportation, different types of silicone are crucial to numerous production processes. Silicones are contained in a wide variety of end-user products — cosmetics, toiletries, lubricants, adhesives and protective coatings, to name a few.

To meet such widespread applications, silicone products come in many different grades, being produced at highly integrated manufacturing plants that use multi-stage processes to deliver consistency and repeatability. The manufacturing process is complex and carefully refined. Silicates in sand or rock are first processed to obtain silicon. Chemical reactions then produce silanes (any of a series of covalently bonded compounds containing only the elements silicon and hydrogen) and, in further steps, polysiloxane precursors (a group of silicon-based polymers), which are the basis for different grades of silicone products.

These precursors contain a silicon-oxygen backbone along with other organic components, and can be processed into silicone oils, resins and elastomers, among other materials. The composition of silicone offers several desired performance characteristics, such as thermal and oxidative stability, chemical inertness and excellent dielectric strength.

Silicone production processes

During the production process, which involves hydrolysis of organohalosilane (carbosilanes derivatized with a hydroxy group on the silicon atom [*1*]) and condensation of chemical compounds forming salts, among other things, silicone manufacturers have to ensure that any unwanted residues and particles are removed, to protect the quality of the finished product. This requirement is met through the use of advanced filtration techniques, which have to be performed without having any adverse impact on volume throughput on the production line. Filtration has to be carried out to exacting standards, using equipment that is reliable and easy to maintain.

Stringent production techniques

One of Europe's silicone manufacturers came to Eaton Corp. (Bloomfield, N.J.; www.eaton.com) with a requirement for a more effective means of carrying out solid separation, as well as liquid traces separation at one of its large production plants. The company was producing about 6,614 lb of intermediate silicone oil at 22 gal/min on a regular basis. The production process involved a carbonation technique using sodium carbonate to neutralize hydrochloric acid. This process resulted in the generation of water residue and solids that need to be removed in an effective way. Failure to do so can increase the viscosity of the final product through the creation of gel in the silicone — identified as a highly undesirable outcome.

Historically, a two-stage process is used. In this process, solids are separated from the silicone intermediate, and water residues are removed using chemical additives. However, the silicone manufacturer wanted to implement a more advanced system that could offer highly controllable removal of solids, traces of water and gel particles in a single-stage operation. By implementing such a unique approach, the company would be able to simplify its production processes, saving time and reducing by-product waste.

FIGURE 1. BECO KD 7 depth filter sheets consist of finely fibrillated cellulose fibers from deciduous and coniferous trees that provide an especially high water-retention capacity

Single-stage filtration process

Engineers from Eaton's Filtration Division forged a strong customer relationship with the silicone manufacturer, working with its technical team to devise an effective solution. The answer came with the combination of BECO depth filter sheets, fitted to a BECO Compact Plate plate-and-frame filtration system, allowing for the removal of nearly all water residue and solids through adsorption, without causing any significant pressure drop on the production line.

In laboratory tests with different types of depth filter sheets, an optimized solution was jointly developed. BECO depth filter sheets have a nominal retention rate ranging from 0.1 to 40 µm, and the analyses identified BECO KD 7 depth filter sheet (Figure 1) as the most suitable grade

for the task at hand. In terms of specific performance characteristics, it has a nominal retention rating of 1.5 μm, making it suitable for filtration of highly deformable particles. The tests showed that the use of 108 ft² of this depth-filter sheet could effectively filter about 6,614 lb of the initial product with approximately 154 lb of cake and less than 2% of residual water.

Such an excellent level of performance was a result of the specific composition of the BECO KD 7 depth filter sheets. This product range is made of pure natural materials and cationic charge carriers. It combines finely fibrillated cellulose fibers from deciduous and coniferous trees with precisely dosed quantities of high-quality diatomaceous earth. A key property of the cellulose fibers is the water absorption capability. In addition, the ideal pore structure of the depth filter sheet allows a reliable retention of gel particles. This enables the BECO KD 7 depth filter sheet to provide the optimal ratio of performance and throughput.

The depth-filter sheets need to be inserted in a reliable filtration system. After assessing available options, the company selected the BECO Compact Plate A600 system (Figure 2). This multi-sheet filter system comes with either an electrically or pneumatically operated hydraulic system.

Quality was an important consideration for the silicone company. The company wanted a reliable filter system that would not cause any unnecessary downtime. This requirement was met through the use of a solid chassis design, with robust filter frames, that ensure that the hydraulic pressure is effectively directed onto the depth-filter sheets. The components of the system are designed to withstand maximum operating temperatures of 249.8°F (121°C), ensuring reliable performance even during extended periods and at high temperatures. The silicone manufacturer also needed a solution that was flexible enough to fit within the restricted space parameters of its production line. The BECO Compact Plate A600 filtration system met this requirement too, offering a highly flexible filter area from 7.10 to 745.94 ft², which allows for customizable solutions for individual applications.

Ease-of-maintenance was also placed high on the specification list. An automatic re-tightening function monitors the actual tightening pressure during operation, because once the depth filter sheets become wet, their thickness deviates, so the system needs to re-press to ensure leak-tight performance. The BECO Compact Plate A600 filtration system can detect changes immediately and automatically adjusts the hydraulic pressure if it falls below a threshold value. Meanwhile, ease of handling and excellent cleanability is achieved thanks to ergonomic design and the use of smooth surfaces. At the same time, a wide range of accessories, such as fittings and riser pipes, meant the system was ready for quick and secure connection.

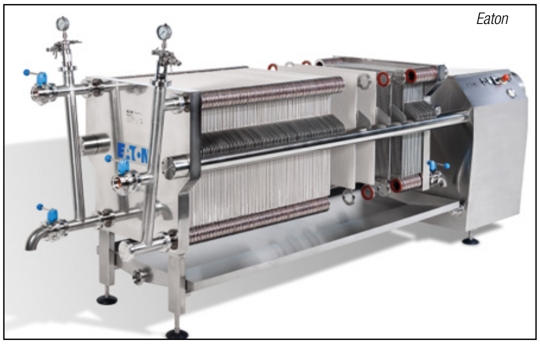

FIGURE 2. The BECO Compact Plate A600 premium multi-sheet filtration system enables silicone manufacturers to increase their product quality and reduce downtimes

Enhancing production efficiency

From the outset, the silicone manufacturer wanted to implement a filtration operation that could remove solids, traces of water residues and gel particles in a single-stage process. This has been successfully achieved with the combination of the BECO KD 7 depth filter sheets and the BECO Compact Plate A600 multi-sheet filter system. Now, solids, water residues and gel particles can be reliably removed in a much shorter space of time than was previously achievable with the two-stage process.

According to Fabrice Doignie, regional sales manager — EMEA within the fine chemical and pharmaceutical sales unit of Eaton's Filtration Division, the project represented a hugely successful collaboration between the technical teams at Eaton and the silicone manufacturer, delivering an excellent result. "It was all about meeting the customer's exacting requirements," Doignie says. "The laboratory screening tests showed that the BECO KD 7 depth filter sheets offered just the right level of filtration, meaning that effective removal of water residues and solids could be achieved at specific volume and flowrates. Meanwhile, the flexibility of the BECO Compact Plate system meant that we could adapt the size of the frames to meet the specified dimensions of the production line. In both cases, the depth of Eaton's product range and the skills of our people meant that we were able to meet the customer's requirements. The project was a true testament to the power of partnership."

Since the installation, Eaton and the silicone manufacturer have forged a successful business relationship, with the company now using other filtration products from Eaton within its production facilities. These include Becopad depth-filter sheets, Becodisc stacked-disc cartridges, and Becodisc activated carbon stacked-disc cartridges. "In each case, we have worked with the customer's development team to provide a solution," Doignie adds. "Ultimately, Eaton has become more than just an equipment supplier. We are now viewed as a manufacturing partner that provides valuable input into production processes, using our engineering knowhow to suggest technology solutions that deliver true added value."

Looking to the future, Eaton believes that the specific properties of the BECO KD 7 depth filter sheet mean it is sure to find further application in the silicone manufacturing industry. "It is a truly unique product solution," Doignie confirms. "The ability to remove water quickly and reliably from another liquid is a highly desirable characteristic. That means we are confident of applying this technology in other production facilities and other market segments across Europe and further afield." ■

Edited by Gerald Ondrey

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Conveyor Selection for Bulk Solids Processes

Use this guide to aid the selection of conveying technologies for applications in powder and bulk solids handling

Josh Marion
Jenike & Johanson Inc.

Many sectors of the chemical process industries (CPI) — including chemicals, plastics, batteries, mining, power generation, plastics, food, agriculture, pharmaceuticals and others — handle a wide range of bulk solids and powders in manufacturing. Research has shown that more than 70% of all products contain ingredients that are handled in bulk solid or powder form at some point during the production chain. Each bulk solid tends to have its own unique characteristics, behaviors and requirements for getting it (and keeping it) flowing and moving through solids handling equipment. Solids-handling equipment, such as bins, silos, hoppers, feeders and chutes have their own set of difficulties and challenges for getting material flowing [*1–3*], and conveyors are no different.

There are dozens of different conveying technologies, many of which may be marketed as a "one-size-fits-all" solution for moving bulk solids around. However, there can be significant consequences if you don't get conveying "right." Depending on your material, application, and conveying technology, you may experience production bottlenecks, flow stoppages and plugging, poor or inefficient transport, product degradation or particle breakage, as well as rapid abrasive wear, segregation and product variability, spillage, dust release, excessive maintenance requirements, or a number of other issues. So when selecting the "best" conveying technology for an application from the start, it becomes essential to cut through some of the vendor claims to mitigate risk of experiencing these handling issues.

FIGURE 1. Several examples of conveying equipment are shown in this solids-handling facility

This article outlines important factors to consider for conveyor selection, and discusses the pros and cons and appropriate use cases for common conveying technologies.

Conveyor types and functions

For the purposes of this article, conveyors are technology or equipment, other than gravity, for moving dry bulk solids through a process. This includes moving solids horizontally, diagonally or vertically, and may involve multiple pickup or discharge points. Unlike bulk solids feeders, conveyors are not choke-fed from a hopper, and they operate only partially full (typically at only 30–50% capacity or less). In addition, they do not meter or control the solids-throughput rate, and generally operate at constant speeds. Feeders tend to be quite short, while conveyors often move materials over significantly longer distances. In fact, there are some belt conveyors used to transport heavy ores several miles overland, with the world's longest belt conveyor system carrying phosphate ore more than 60 miles (97 km) from a mine in the Sahara desert to a shipping port [*4*].

Proper design and selection of bulk-solids feeders, as well as attending to details of how feeders interface with conveying systems are also extremely important for ensuring reliable process operation and avoiding bottlenecks, but are beyond the scope of this article.

Conveying technologies come in a wide number of shapes, sizes and configurations. Some of the most common types include the following:

- Pneumatic conveyors
- Screw conveyors
- Belt conveyors
- Bucket elevators
- Vibratory conveyors
- Drag chain and cable conveyors
- Fluidizing conveyors (for example, airslides)

A typical industrial process with a number of these technologies is shown in Figure 1. The list above is only a partial listing of conveying technologies, and there is significant variety and specialized conveyors with unique features within each of these categories. Regardless of what type of conveyor you use to move your material, all conveyors should meet the following requirements:

- Reliable transfer of the material from the pickup point(s) to the delivery point(s), at the required flowrate, with no pluggage or material buildup within the system
- Minimal product degradation or particle breakage, if required
- Minimal abrasive wear
- Reasonable energy consumption
- Safe operation with minimal spillage and dust release
- Sensible maintenance intervals, with minimal operator intervention required between intervals
- Sufficient flexibility to fit within the available space

Conveyor selection criteria

When selecting what type of conveyor to use in a given application, it is important to ask some of these critical questions:

Material properties. Is the solid material free-flowing? Cohesive and sticky? Frictional? Fine, dusty and aeratable? Friable/breakable? Abrasive? Corrosive or reactive? What's the bulk density? What is the particle-size distribution, including the largest clump or lump size? Could the material's characteristics

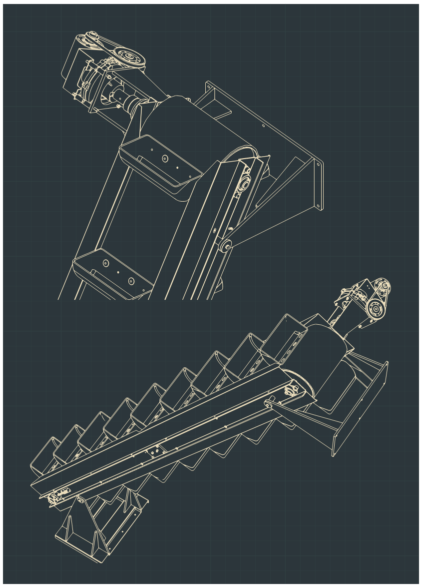

FIGURE 2. Bucket elevators, like the one shown in the diagram here, transport material in discrete buckets attached to a chain or belt

change over time, for example, due to variable moisture content? Or would the conveyor handle multiple different materials?

Required capacity or throughput. Does the conveyor selected have sufficient capacity, such that it can transfer material from all pickup points to all delivery points, without acting as the rate-limiting step in the process? Could there be surges or fluctuations in throughput due to upstream processes? And does the conveyor have sufficient capacity to accommodate those surges? Could the production rate possibly increase in the future?

Facility layout requirements. How far does the material need to travel between pickup and delivery? Is it a relatively "straight shot," or does the route require a lot of twists and turns around corners or interferences? Is required conveying mostly in the horizontal direction, or is there a large amount of vertical lift required? Does the material need to be elevated in a relatively small footprint? Is there sufficient footprint and headspace available for the conveyor to fit? Are there multiple pickup points and multiple delivery points, or could more be added in the future?

Process conditions. For example, is the material or gas near ambient temperature, or at very high temperatures? Will there be significant temperature swings?

Special safety considerations. What happens if the material is not well-contained and dust is released or spillage occurs? Is the material toxic? Is it a respiratory hazard? Are there combustibility or explosibility issues? Or even just a housekeeping nuisance? Does the solid material need to be handled under inert gas to prevent combustion, oxidation or other reaction?

Potential for foreign-material contamination. Could there be undetectable pieces of plastic or nonmagnetic metals that could break or wear off in the conveyor and contaminate your product? This is of special concern for handling food or pharmaceutical products.

Particle degradation and breakage. Would particle degradation and breakage impact product quality or material flowability? Could there be issues with product cross-contamination?

Discharge characteristics. Would batch or pulsatile discharge affect your process, or do you need a consistent, steady stream? Some conveyor types tend to discharge material in periodic fluctuations or pulsations, while other types of conveyors are better-suited for delivering a consistent, steady, continuous stream to downstream equipment.

Conveyor cleaning. Does the conveyor need to be cleaned out completely (for example, between grade or recipe changes), or is it acceptable to have some residual material left in the conveyor even after it is emptied? Does the conveyor need to be cleaned out or washed down frequently for sanitary purposes?

Costs. Have you considered the operating costs over the life of the conveyor, and not just the initial upfront capital costs to purchase and install the equipment? Some factors that can drive higher operating costs (opex) are higher energy costs to move the material, poor operation and unreliable conveyance that requires more operator intervention and reduced production, more frequent maintenance requirements due to component breakdown and erosion over time, and downtime to fix defective parts. Many mechanical conveyors, such as screws and belts often have higher upfront capital costs (capex) compared to pneumatic conveyors, but they also

TABLE 1: COMPARISON OF CONVEYOR TECHNOLOGIES WITH "STANDARD" FEATURES*								
Consideration	**Pneumatic (dilute phase)**	**Pneumatic (dense phase)**	**Belt**	**Screw**	**Bucket elevator**	**Tubular drag (cable/ chain)**	**Drag chain**	**Vibratory**
Materials conveyed	Most	Limited	Most/all	Most	Limited	Limited	Most	Most
Capacity	Low (< 30 ton/h)	Moderate (<300 ton/h)	Extremely high (<5,000 ton/h)	High (<600 ton/h)	Very high (std. <1,000–2,000 ton/h)	Low (<100 ton/h)	High (<1,000 ton/h)	Low (<100 ton/h)
Distance	Long (<1,000 ft)	Very long (<2,000 ft)	Extremely long (near unlimited)	Moderate (<100 ft)	Long (<300 ft)	Moderate (<300 ft)	Long (<500 ft)	Short (<50 ft std.)
Vertical lift	Excellent	Excellent	Poor	Poor	Very good	Good	Moderate	Very poor
Layout flexibility, horizontal-turns/corners possible?	Excellent	Excellent	Very poor	Poor	Very poor	Good	Very poor	Limited
Cohesive, sticky materials	Good	Very poor	Excellent	Moderate to good	Moderate (avoid digger designs)	Very poor	Moderate	Fair to good
Highly abrasive materials	Very poor to poor	Moderate	Excellent	Moderate to good	Good (avoid digger designs)	Very poor to poor	Good	Excellent
Dust containment	Excellent	Excellent	Fair, if enclosed	Very good	Moderate	Excellent	Good	Poor to excellent
Toxic materials	Excellent	Excellent	Very poor	Very good	Moderate	Very good	Moderate	Good, if enclosed
Particle degradation	Very poor	Fair to good	Good	Poor to fair	Poor	Excellent with cable, Poor to fair with chain	Poor	Excellent
Cleanable/sanitary	Excellent	Excellent	Poor	Poor to moderate	Very poor	Good to excellent	Very poor	Excellent
Maintenance requirements	Very low	Low	Moderate	Moderate	High	Moderate to High	High	Very low
High temperatures	Excellent	Excellent	Very poor	Excellent	Excellent	Fair	Excellent	Excellent
Ability to use inert gas	Excellent	Excellent	Avoid	Good	Good	Excellent	Good	Good
Cross-contam./cleanout	Excellent	Excellent	Good	Very poor	Poor-Good	Good	Very poor	Very good
Multiple inlets possible?	Excellent	Poor to good	Excellent	Excellent	Very poor, if digger design	Excellent	Excellent	Very poor
Multiple outlets possible?	Excellent	Excellent	Poor	Good, with gates	Very poor	Excellent	Good, with gates	Very poor
Steady/continuous feed	Excellent	Poor	Excellent	Moderate	Poor	Moderate	Good	Excellent
Upfront capital cost	Low	Moderate	Moderate to high	Moderate to high	Moderate	Moderate	Moderate to high	Moderate
Specific energy cost	Very high	Moderate	Very low	Low	Low	Low	Low	Very low

*Specialized conveyors in each category may have unique features and expanded capabilities

generally have much lower energy costs, which reduces opex. On the other hand, mechanical conveyors also have more moving parts and are typically more maintenance-intensive that pneumatic systems. If the mechanical conveyor is not properly selected for your application, frequent maintenance requirements could significantly increase the conveyor's opex, so that the mechanical conveyor could ultimately cost more in the long run. Additionally, some lower-capex mechanical conveyors may be more prone to erosion, breakdown or failure versus other lower-capex mechanical conveyors, so a lower-capex conveyor may actually have much higher opex and may cost you more over the life of the equipment compared to a scenario where you spent a little more up-front. It's all a balancing act.

So, now with those questions and considerations in mind, how do you move ahead in selecting a conveyor? The next sections of the article explore the features, advantages and disadvantages of some of the most common conveyor types. Note that "standard" features are discussed for each category. There are many specialized features and other conditionals that could improve each conveyor's characteristics and capabilities.

Pneumatic conveyors

Pneumatic conveying involves using air or another gas to transport the solid material through a pipeline, at moderate to high velocities. Pneumatic systems are often highly attractive, since they generally have low capex, and they are also by far the most flexible conveying technology from a layout standpoint. Pneumatic systems can easily support multiple pickup and delivery points and it is fairly simple to route piping through a plant. Also, pneumatic systems do not occupy a lot of space, and it is easy to run both horizontally and vertically. They can often use existing pipe racks or supports, and can be run over long distances.

There are two main modes of pneumatic transport:

• *Dilute-phase* — Particles are fully suspended in the conveying gas, at relatively low pressures drops, high velocities, and low solids loadings (typically 3–15 psig and 50–80 ft/s or more at pickup).

• *Dense-phase* — Particles are only

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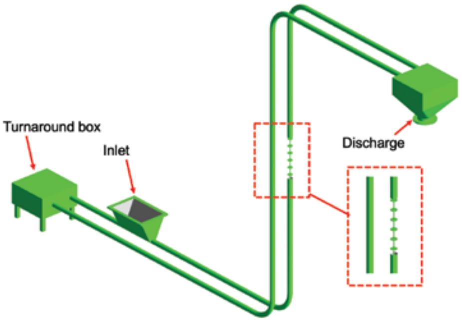

FIGURE 3. Tubular drag conveyors pull material through a pipe using pucks or discs attached to a continuous cable or chain

partially suspended in the gas, at high pressure drops and lower velocities, and at much higher solids loadings (typically 25–150 psig and 10–40 ft/s at pickup). Dense-phase conveying also has two discrete regimes, each of which are suitable for very different materials and applications: moving-bed ("dune" flow), which is often used for conveying fine, aeratable and free-flowing powders like alumina or cement, and piston-plug flow, which is often used for conveying coarse, highly permeable materials like plastic beads or catalyst pellets.

Both dilute- and dense-phase can be done using either positive pressure gas to "push" the material through the line towards the delivery point, or using a negative pressure (vacuum) to "pull" the material through the line. The main advantages of pressure systems versus vacuum systems are that pressure systems can transport higher tonnages (up to 300 ton/h for pressure, compared to only up to 100 ton/h for vacuum), over longer distances (up to 1,000 ft for pressure versus only about 200–300 ft for vacuum), and at lower velocities, and pressure. Also, pressure-based systems are well-suited for conveying under inert gases and preventing air/oxygen ingress. The main advantages of vacuum conveying are that all leakage occurs inward, making it highly attractive for containing toxic dusts. Vacuum systems are also very well-suited when there are many pickup points and a single delivery point (for example, in dust-collection systems).

Table 1 includes a comparison of the main features, advantages and disadvantages of dilute- and dense-phase pneumatic transport, along with how they compare with a number of different common mechanical conveying technologies. One additional potentially major disadvantage of pneumatic systems to consider is that they require additional dedicated filter equipment (such as cyclones, baghouses, cartridge filters) for separating the material out of the conveying gas stream, whereas mechanical systems generally do not.

Mechanical conveyors

The major features and limitations of several types of mechanical conveyors are included in Table 1. Typical applications for some of the most common technologies are summarized below.

Belt conveyors. Belt conveyors are used for transporting a massive range of products in a wide variety of industries, from fine food and chemical powders, up to heavy coarse ores from mining operations. One of the main strengths of standard belts is their ability to convey extremely high tonnages over long distances, while some of their main drawbacks are that they are generally not very good at containing dusts, are not very flexible from a layout standpoint, and are not suited for quickly elevating or lifting material vertically. Typically, relatively shallow inclines only up to about 15 deg are acceptable, meaning long distances are required to lift material. Specialized types of belts are available (for example, chevron or cleated belts, pocket belts, sandwich belts, tube belts) which can better contain dusts, may have better layout flexibility and ability to navigate around turns and corners, and can convey up steeper angles.

Screw conveyors. Like belts, screw conveyors are used in a huge array of applications and with materials across most industries, but they are generally not suited for "heavy duty" applications with heavy, coarse, abrasive materials like ores and minerals. The main strengths of screws are their cost-effectiveness and mechanical simplicity, as well as their ability to contain dusts, while their main drawbacks are their limited length, their generally poor layout flexibility, and their relatively low capacity compared to other types of mechanical conveyors. Also, solid material "grinds" as it moves through the screw, which can cause significant particle breakage or degradation with some materials. Standard screw conveyors also tend to have more residual material left in the conveyor than other types of conveyors, even when they're "empty" due to "dead" material that remains at the bottom of the screw trough, which can create cross-contamination issues.

Screws come in a number of specialized configurations, including flexible screws that can convey material up relatively steep inclines, vertical screws that can elevate some materials over relatively small distances up to about 20 to 30 ft, coreless, ribbon-flighted screws, which are more resistant to buildup of sticky materials. There are also screws that have some blending capability that can be used in some applications, and some screws that can be used for heating or cooling during transport. Some screws are also available with "drop-bottom"

troughs to facilitate more complete cleanout, and limit cross-contamination risk.

Bucket elevators. Bucket elevators (also known as "legs") transport material in a series of small, discrete buckets attached to a chain or belt, and are most often used in the food and agricultural, chemical, and consumer-goods industries (Figure 2). In the most common configuration, at the infeed, buckets dig material out of the bottom of the conveyor (the "boot") as they round the tail sprocket and begin to lift material vertically up. Then, centrifugal force ejects material toward the outlet as the buckets round the head sprocket at the top of the conveyor. These digger-type and centrifugal-discharge elevators should not be used with materials that are cohesive, breakable, or abrasive because the digging action can compact the material in the boot, cause significant particle breakage and degradation, and lead to rapid wear of the chain, sprocket and the buckets themselves.

There are also continuous bucket elevator configurations designed to overcome some of the issues with cohesive, friable or abrasive materials. In this type of elevator, the buckets are generally fed horizontally (rather than vertically) and there is no separation between buckets, an effort to avoid the digging action in the boot and allow more gentle feed and discharge. At the discharge in centrifugal designs, material is ejected from the buckets toward the outlet as the buckets come around the head sprocket at the top, while other designs instead allow the buckets to rotate and tip over as they reach the discharge, to dump out material more gently than the high-velocity throwing motion in centrifugal designs.

Bucket elevators' main strengths are their ability to convey high tonnages, to quickly elevate materials to large heights, and continuous bucket designs can be very gentle on the product and minimize degradation. The major drawback is that bucket elevators are generally the most maintenance-intensive conveying technology. Even with "heavy-duty" construction, they frequently experience issues with chains breaking or coming off the sprockets over time, particularly with digger-type bucket designs.

Tubular drag conveyors. Tubular drag conveyors (Figure 3) pull material through a pipe or tube using a series of equally spaced slow-moving pucks or discs attached to a continuous cable or chain, with drive and turnaround sprockets at either end of the conveyor. They are most often used in the food, chemical, consumer goods and chemical industries for cost-effective, well contained or enclosed (for minimal dust release), gentle transport of powders with minimal degradation. The main strengths of tubular-drag systems are that they require relatively low capex, they have the most layout flexibility of any mechanical conveyor and can make up to 2–3 turns horizontally and vertically within a single conveyor. They also allow complete containment or enclosure to minimize dust release, and their low velocity minimizes particle degradation or breakage. They can easily support multiple feed and discharge points.

One of their main drawbacks is they tend to be somewhat maintenance-heavy when not properly applied. First, they are generally not built as "heavy duty" as other mechanical conveyors types, so they are often not well-suited for applications with heavy, abrasive materials. They should also not be used with cohesive solid materials, because the material tends to build up on the tube walls and "smear." With chain-driven types, sticky material often builds up on the chain over time. With cable-driven designs, tension causes the cable to stretch out over time, so the pucks do not properly mount in the turnaround sprockets and eventually derail the cable. The cable frequently needs to be re-tensioned and periodically replaced. With chain-driven types, the chain is also prone to derailing from the sprockets, because it often becomes twisted as the conveyor repeatedly turns, and with cohesive materials, buildup on the chain can prevent the pucks from properly mounting in the teeth of the drive and turnaround sprockets (although there are optional brush features to attempt to reduce some of this buildup). When the pucks get derailed, the conveyor needs to be shut down to untwist the chain and remount the pucks.

Concluding remarks

While dozens of different conveying technologies are available, and the technologies have improved over the years, no single "best" conveyor for moving all bulk solids exists. All of today's technologies have particular strengths and weaknesses. The most appropriate conveyor is intensely dependent on the solid material being conveyed and your process. To minimize the risk of production bottlenecks due to poor conveyor operation, product-quality issues, or issues with high operating cost due to significant maintenance requirements, when choosing your conveyor, it is essential to consider your material's characteristics by measurement in a qualified testing laboratory using proven scientific methods [*5–8*], as well as your specific process conditions and application needs. ■

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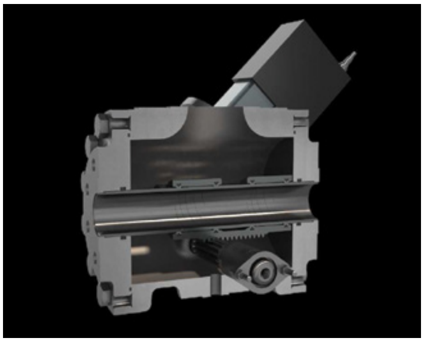
Author

Josh Marion is a senior project engineer with Jenike & Johanson, Inc. (400 Business Park Dr., Tyngsboro, MA USA 01879, Phone: +1-978-649-3300, Email: jmarion@jenike.com). In nine years at Jenike, Marion has worked on hundreds of projects for designing new bulk-solids-handling systems and developing customized retrofit modifications for existing installations to ensure reliable material flow and transport. Marion received B.S.Ch.E. and M.S.Ch.E. degrees from Northeastern University in Boston, Mass.

Achema (www.achema.de), the global forum for the chemical engineering and process industries presented by Dechema e.V. (www.dechema.de), is taking place August 22–26 in Frankfurt am Main, Germany. This year's event will feature over 2,000 exhibitors spread out over 12 exhibit halls and a comprehensive technical program. Focal topics for the event include: product and process safety; digitalized laboratories; and modular and connected production. This year, several co-located events will expand the breadth of topics at Achema, including: Climate-Neutral Chemical Industry 2050; Automation in Dialog; International Powder and Nanotechnology Forum (IPNF) 2022; and the Information Platform for Plant Engineers. This show preview covers a small selection of the products and services that will be showcased by Achema's exhibitors.

Heat slurries without plugging or fouling

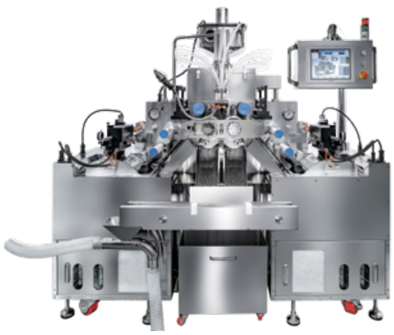
The Non-Obstructing Heater (NOH; photo) features a straight-tube design that allows for unrestricted flow, prevents pressure drop, and heats slurries without plugging or fouling. In addition, the NOH's rugged design and construction materials enable it to handle viscous slurries, particulate-filled products, abrasive or corrosive substances and stringy products, along with inline water-heating abilities. Compared to other heating systems, the NOH utilizes a smaller footprint, with direct installation into the existing system piping and does not require special tools for maintenance. Ranging in size from 2 to 12 in. (DN50 to DN300), volumetric flow capabilities reach up to 6,900 gal/min (1,567.2 m^3/h). Hall 6.1 Booth A94 — *Hydro Thermal Europe Corp., Lyon, France*
www.hydro-thermal.com



Hydro Thermal Europe

Processing machines for soft-gel encapsulation and drying

Demand for vegetable-based soft-gel products is rapidly increasing, and in response, this company has developed special machinery for vegetable soft-gel processing. The PNF Softgel SE-100 Series soft-gel encapsulation machine (photo) is designed with advanced functions, such as a servo-control filling system, gelatin level sensor and easy cleaning and maintenance. Additionally, the PnF Softgel Model CTD-10 drying conveyor is a new system that makes it possible to produce high-quality vegetable soft gels by removing more than 5% of the humidity from the soft-gel media before transferring to the dry tumbler. Hall 3.1 Booth G69 — *Countec Ltd., Gyeonggi-Do, South Korea*
www.countec.com



Countec

Skid-mounted plants for continuous processes

This company offers skid-mounted systems (photo) comprising an assembly of interconnected module-based units. Depending on the process needs of the plant skid, a variety of pre-engineered modules can be selected and combined with application-specific modules to deliver high process performance from the final turnkey plant system. This approach reduces investment costs and enables fast project realization. A particular use case for these modular skids is a continuously operating modular API and intermediates synthesis plant that was recently put into operation to realize the benefits of process intensification. It consisted of two feed modules with two dosing lines each designed for a flowrate between 15 and 250 mL/min at 20 bars. The plant can operate with liquids, gases and suspensions as feedstreams, and it can be used with various continuous-reactor technologies while operating automatically. Hall 9.1 Booth E64 — *Microinnova Engineering GmbH, Allerheiligen bei Wildon, Austria*
www.microinnova.com

Microinnova Engineering

Full-service units for sterilizing laboratory wastewater

From the disposal of samples to the washdown of equipment, the sterilization of liquid waste is crucial in laboratories. The Effluent Decontamination System (EDS; photo) is a miniaturized wastewater-sterilizing plant for laboratory use. Using penetrative heat, the

AstellBio

Haver & Boecker Maschinenfabrik

Andritz Separation

Eaton Technologies

Gneuss Kunststofftechnik

thermal EDS units neutralize all biologically active material, no matter the clarity of the wastewater. This technique of thermal sterilization provides a simple method of decontamination, requiring only the input of electricity. The Micro EDS model is capable of sterilizing 9 L of wastewater every 45 min, and can be connected into the effluent output of a wide range of appliances. Other models in the range include the Sink, which provides a fitted basin and automatic tap, and the Sink & Autoclave Combo, which allows instruments and solid waste to be sterilized simultaneously with the wastewater. Hall 4.1 Booth E37 — *AstellBio, Kent, U.K.*
www.astellbio.com

A dewatering centrifuge for challenging feed conditions

The new HX screen-scroll centrifuge (photo) is designed to enable flexible dewatering for a broad variety of feed material without compromising operations, even under difficult feeding conditions. This centrifuge is especially suitable for processing bulk chemicals and agrochemicals. The combination of unique features, such as a modular scroll and an express cartridge with high-performance technologies like this company's Gentle Feeder feeding system, increases uptime and product quality at the same time. Varying feed conditions or interrupted feeding can be handled effectively, and process performance is not affected as long as certain minimum requirements are met. Hall 12.0 Booth C19 — *Andritz Separation GmbH, Graz, Austria*
www.andritz.com/separation

These activated-carbon filter sheets require no manual dosing

The new generation of Beco Carbon depth activated-carbon filter sheets (photo) offers particularly high adsorption for liquid filtration. Having the activated carbon bonded directly into the filter eliminates the need for manual dosing and separation of the otherwise typically loose activated carbon, and the challenges that go along with it. With their strong decolorization abilities and adsorptive removal of undesired byproducts, along with taste, odor and color correction, these filter sheets are well-suited for use in the fine chemical, pharmaceutical, cosmetic, food-and-beverage and biotechnology industries. Beco Carbon depth filter sheets are available in different versions: ACF 02 with an activated carbon content of 1,000 g/m^2 (macroporous); and ACF 07.10 with 420 g/m^2 activated carbon content (meso/macroporous). They are available as stacked disc cartridges and small disposable capsules in all common sizes. Hall 12.0 Booth D22 — *Eaton Technologies GmbH, Langenlonsheim, Germany*
www.eaton.com/filtration

Hermetically sealed bagging for a wide range of powder products

With the clean and weatherproof ADAMS range of bag-filling technologies (photo), powder products from a number of industry sectors, including building materials, minerals, chemicals, food, pharmaceuticals and cement, are filled into preformed bags made from a continuous tubular film. During filling, air is extracted from the bag with the aid of a vibrating lance and a compactor. Next, the packaging itself is hermetically sealed, resulting in completely sealed and very compact bags. Hall 3.0 Booth F38 — *Haver & Boecker Maschinenfabrik, Oelde, Germany*
www.haverboecker.com

This reactor is designed for fast and efficient polymer recycling

Specially developed for polymer recycling, the JUMP polyreactor (photo) is a compact, quick and efficient alternative to conventional solid-state systems. The reactor enables direct reintroduction of melt-phase polymers into production processes without the need to remelt the polymer. The reactor is installed directly behind this company's processing units, where the polymer passes over several rotating, stirring and conveying elements, to create a polymer film whose surface is constantly renewed. The reactor vessel is kept under vacuum, through which volatile substances are reliably removed. By regulating the residence time in the reactor, as well as the vacuum, the fill level and the speed of agitation, the polycondensation reaction can be altered to achieve the required product properties, such as viscosity. Hall 12.0 Booth C2 — *Gneuss Kunststofftechnik GmbH, Bad Oeynhausen, Germany*
www.gneuss.com

A patented coupling technology for diaphragm seal systems

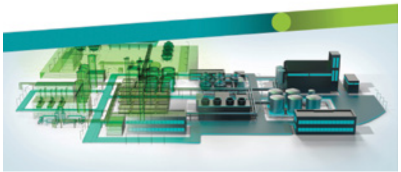
Labom Mess- und Regeltechnik

The patented REconnect fast-coupling device (photo) provides simple and safe decoupling and recoupling of diaphragm seal systems. A REconnect device is installed between the measuring device and the process connection to facilitate handling when measuring systems are mounted with a capillary, such as on vessels with large heights, when there is restricted space or in plants that are difficult to access. Operated by a special lock, it makes safe and leakage-free decoupling of diaphragm seal systems possible without affecting oil volumes and without loss of oil or intake of air. This means that the process no longer has to be opened to replace or calibrate measuring instruments, because the diaphragm seal remains connected to the process. Subsequently, the measuring device and diaphragm seal are just as easily recoupled and the plant can immediately be put back into operation. This special separation process makes it possible to repeat the procedure as many times as necessary. REconnect also offers a solution for mobile vessels making it unnecessary to dismantle all the measuring systems, while autoclaving vessels, for example. Hall 11.1 Booth F46 — *Labom Mess- und Regeltechnik GmbH, Hude, Germany*
www.labom.com

Large automated machines, in a virtual environment

Optimal Industrial Automation

At Achema, this company is showcasing an interactive virtual experience (photo) that will highlight its advanced automation capabilities, allowing visitors to explore 3D models of key applications and learn how bespoke, automated machines can improve throughput. Attendees will have access to photorealistic, 3D renderings of large pieces of equipment that would not be accessible on a physical stand. They will be also able to interact with the machines. Hall 11.0 Booth E42 — *Optimal Industrial Automation Ltd., Bristol, U.K.*
www.optimal-ltd.co.uk



Phoenix Contact

Rembe

EagleBurgmann Germany

Innopharma Technology

Lindor Products

Seamless engineering and monitoring packages

This company's Module Type Packages (MTPs) can be integrated into overarching production systems. Such packages can be adjusted repeatedly to adapt to changing market requirements. At Achema, this company will present a joint use-case with X-Visual Technologies GmbH, Semodia GmbH, ABB AG and Wotten Consulting that will illustrate process engineering through module orchestration (photo). In cooperation with Seepex, another demonstration will show how a smart dosing pump can be automated easily with the MTP Designer system. MTPs can also interact with Namur Open Architecture (NOA) — a live demonstration at Achema will show how the sensor technology of an agitator tank sends monitoring and optimization data to the control center via the NOA-side channel. Hall 11.0 Booth G4 — *Phoenix Contact GmbH & Co. KG, Blomberg, Germany*
www.phoenixcontact.com

Overpressure protection for low-pressure tanks

The Elevent breather valve (photo) protects vessels with low design pressures against overpressure and vacuum in a pressure range of 2 to 200 mbarg. This makes it appropriate for low-pressure vessels inside storage tanks, dryers and other vessels in the chemical, pharmaceutical and food industries. For example, Elevent is ideal for use in dryers in which free-flowing process media, such as cocoa, raw tablet materials or teas, are processed under vacuum. If the vacuum pressure inside the vessel begins to drop, the valve opens and thus ensures targeted pressure equalization, which is of immense importance both for the stability of the dryer, as well as the quality of the sensitive substances inside. Controlled maintenance of the pressure level is achieved via a very low leakage rate. This prevents both emissions of volatile gases or other environmentally harmful substances, as well as the formation of explosive mixtures or a potentially dangerous ingress of air. Hall 9.1 Booth C4 — *Rembe GmbH Safety + Control, Brilon, Germany*
www.rembe.de

Agitator seals optimized for side- and bottom-entry drives

With its recently upgraded design, HSMR34 is a double-acting liquid-lubricated mechanical seal (photo) that is approved for use in all explosive environments according to the ATEX Directive. The standard material used is silicon carbide (SiC) in a hard/hard pairing. Especially in machines with a side or bottom entry drive, the medium is pressed against the sealing gap, posing unique challenges for the seal design, and increasing the risk of buildup. To solve this problem, HSMR34 mechanical seals are equipped with a solid counter-ring that extends far into the product. In addition to excellent heat dissipation, this also has another advantage — the rotation of the counter-ring produces centrifugal forces that keep material from accumulating in the sealing gap. An O-ring integrated into the solid counter-ring separates the shaft from the product, ensuring that the shaft sleeve has no contact with the product and opening up new options for shaft sleeve materials. Special Outdoor Area 10 Booth A7 — *EagleBurgmann Germany GmbH & Co. KG, Wolfratshausen, Germany*
www.eagleburgmann.com

This data platform supports automated fluidized-bed systems

SmartX (photo) is a process digitalization and automation platform for fluidized-bed operations that is built for real-time intelligence and process control, supporting pharmaceutical process development from studies and design of experiments (DoE) to scaleup and manufacturing. This platform provides secure storage, advanced analytics, process insights and flexible automation tools that ensure efficiency, productivity, process robustness and patient safety in every dose. A deployed SmartX system enables process automation through low-code/no-code interfaces, placing the control evenly across all divisions, from research and development to production, whereby every employee and every process can be empowered with the manufacturing data that SmartX yields. Hall 11.1 Booth G10 — *Innopharma Technology Ltd., Dublin, Ireland*
www.innopharmatechnology.com

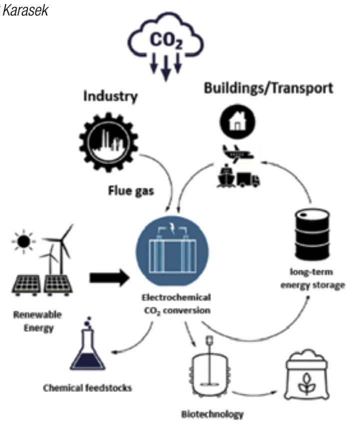
Large-scale drum blenders protect product integrity

The L25000 industrial mixer (photo, p. 50) blends up to 25,000 L (15 tons) of dry product with six specially designed blades, allowing each particle to gently flow along its own path without heating up. This results in a fully homogenized, high-quality blend for a large range of products, including gelatin, super adsorbent powders (SAP), polymer compounds, vegetable seeds, metal injection-molding (MIM) compounds and more. The manufacturer announced the world's largest drum blender — an L25000 model — was recently installed at a collagen production site in southern France (photo). Hall 12.0 Booth D83 — *Lindor Products B.V., Dordrecht, the Netherlands*

www.lindor.nl

This research project is piloting electrochemical CO_2 recycling

GIG Karasek



This company, along with Johannes Kepler University (JKU) Linz, has initiated a research cooperation project aimed at reducing CO_2 emissions through the development of novel catalysts and the construction of a pilot plant for testing and optimizing processes to recycle CO_2 through electrochemical reduction into basic chemicals, such as CO, formic acid and acetic acid, and fuels, such as hydrogen, methane, methanol and ethanol (photo). The first plant with several cells connected in series should be ready for industrial use by the end of 2023. The pilot plant will, in turn, provide the basis for the design and dimensioning of large-scale industrial plants. A market launch will then be possible based on this scaleup concept. Hall 4.0 Booth H24 — *GIG Karasek GmbH, A Member of Dr. Aichhorn Group, Gloggnitz, Austria*

www.gigkarasek.com

Increase pump safety with secondary containment options

This company's magnetic-drive pumps have a primary containment shell, which can be monitored using a patented shroud-temperature monitoring system that indicates undesirable operating conditions effectively and quickly. In many applications, this safety option is sufficient. However, certain applications require additional measures to prevent the pumped fluid from being released upon a failure of the primary containment shell. This company designed and qualified a secondary contain-


CP Pumpen

ment system (photo) consisting of a radial shaft-seal ring (RSSR), which uses a pressure or leakage detector for monitoring. It is able to withhold pressures up to 16 bars with a rotating shaft up to 3,600 rpm and for temperatures ranging from –80 up to 250°C. The secondary barrier option is available for both close-coupled or frame-mounted designs. It provides an additional safety feature and makes the magnetic-drive pumps suitable for safety-critical applications with additional requirements for a secondary containment. Hall 8.0 Booth F28 — *CP Pumpen AG, Zofingen, Switzerland*
www.cp-pumps.com

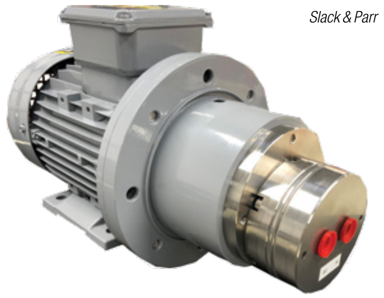
Improved ball valve with enhanced security features

The 543 Pro ball valve (photo) is used for mixing and distribution in water treatment, chemical and pharmaceutical processes. On a mechanical level, the three-way ball valve increases safety with a new lever that prevents unintentional operation thanks to a locking ring. For an extra layer of security, a padlock can also be fitted in order to protect the valve against unauthorized usage. These improvements enable safe and uninterrupted operation of piping systems. Another new feature for the 543 Pro is the addition of new stems with a predefined breakpoint between the actuator and ball valve. In the event of a blockage within the system, the breakpoint ensures that only the stem has to be replaced, rather than the entire ball valve. This reduces downtime and saves costs. Hall 8.0 Booth E64 — *Georg Fischer Piping Systems Ltd., Schaffhausen, Switzerland*
www.gfps.com

Georg Fischer Piping Systems


Metering pumps for high-pressure, low-viscosity fluids

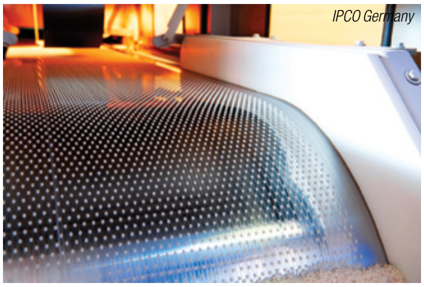
As part of this company's Pulseless Flow range of high-precision gear-metering pumps, the SPLV model (photo, p. 53) has been designed to pump low-viscosity fluids, including acids, solvents, resins and water, even under high pressure while maintaining constant levels of speed and accuracy throughout the process. Pulseless Flow pumps are built around hardened steel involute gears that are machined to precise tolerances of one or two microns. This results in extremely small, controlled clearances between the gear and mating components, ensuring almost no internal slip even at high pressures. This level



of precision means the pump is able to control and meter the flow with extreme accuracy and repeatability under differential pressures of up to 50 bars. The pumps are built with gears engineered entirely from martensitic stainless or cobalt-chromium steels for optimum strength and dimensional stability. According to the manufacturer, these are the only precision pumps in the market built specifically to address the characteristics of low-viscosity fluids in high-pressure applications. Hall 9.0 Booth B26 — *Slack & Parr Ltd., Derby, U.K.*
www.slackandparr.com

Granulate a wide range of chemical melts

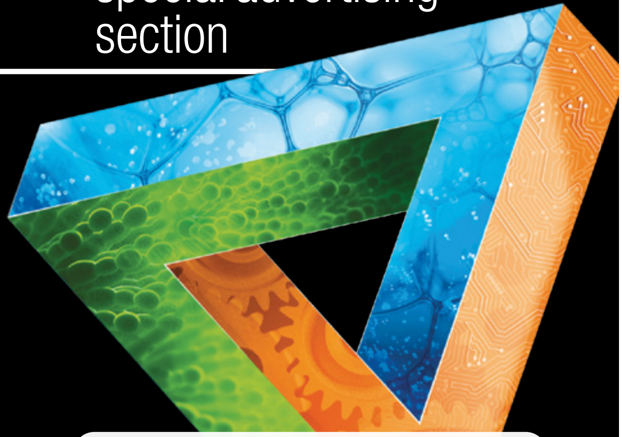
This company has continued to evolve its Rotoform granulation system (photo) through 11 different models, each designed to meet the requirements of a specific group of chemical melts. Chemical melt is delivered to the Rotoform unit and deposited onto a continuously running steel belt in drop form. Heat is transferred via the steel belt to cooling water sprayed against the underside of the belt, resulting in controlled solidification and the production of free flowing, uniform pastilles, an ideal form for subsequent storage, transportation, dosing and mixing. At the heart of the range is the Rotoform 4G, which is used for solidification of low- and high-viscosity melts. Other members of the 4G family have been developed for handling abrasive and sedimenting materials (such as catalysts and suspensions), melts requiring high feed temperatures (such as bitumen or resins) and the pastillation of subcooling melts (photochemicals). Easy



cleaning and stainless-steel construction also hygienic operation. The Rotoform process is clean, dust-free and energy efficient, and its indirect cooling method eliminates any risk of cross-contamination between the product and cooling media, so there is no wastewater. Other recent updates include the availability of optional remote diagnostics, a system that allows users to grant temporary access to live data so that technicians can diagnose and resolve issues quickly. Hall 4.0 Booth D4 — *IPCO Germany GmbH, Fellbach, Germany*
www.ipco.com ■

Mary Page Bailey

ACHEMA
special advertising section



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Continuous Flow Catalyst Testing Made Easy

Parr Instrument Company's new Continuous Flow Tubular Reactor is compact, pre-assembled, and configurable with a user-friendly touchscreen interface and easy installation.

This continuous tubular reactor system includes up to four gas mass flow controllers, a gas purge line, and optional liquid pump. User-adjustable high temperature and pressure alarms are tied to safety interlocks which automatically shut down the furnace, stop reactant flows, and optionally flush the reactor with inert gas.

The system comes standard with an intuitive touchscreen interface for control, monitoring, and logging of three heated zone temperatures, gas flow rates, and monitoring and logging of pressure data. The three independently controlled heated zones with centerline multipoint thermocouple enable controlled reactant preheat and better control over catalyst bed temperatures.

Reactors are available in the materials **Parr** has come to be known for in their stirred reactors, including 316SS, Alloy C-276, Titanium, and Alloy 600. Standard reactor sizes available include inside diameters of 7, 9.5, 25, and 36 mm, with lengths of 305, 610, and 915 mm. Cooling condenser, gas/liquid separator, and manual back pressure regulator are included.

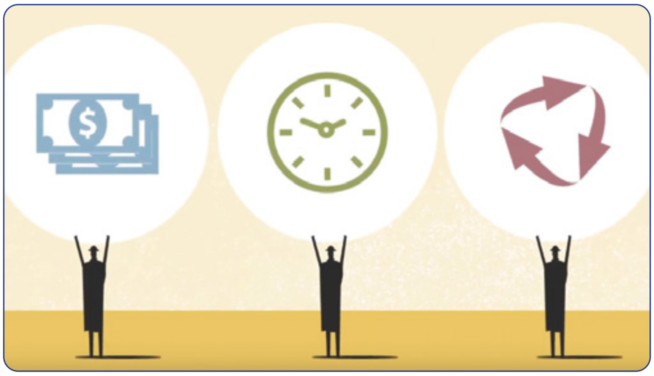
When combined with Parr's new catalyst loading toolkit, continuous flow catalyst testing has never been easier. This indispensable catalyst loading toolkit includes a centering solids funnel and tools for uniform repeatable loading of catalyst or other bulk solids in the reactor annulus while easily adjusting and measuring the location and length of the packed bed.

For more information about Parr's 5420 tubular reactor with touchscreen visit: **https://www.parrinst.com/5420**

Getting the Most Value from a Process Simulator

Using a process simulator isn't always a matter of building and specifying detailed flowsheets. To get the most value from your simulator, try exploring new ways to use its features to support your day-to-day needs as a chemical engineer. For example:

- **Plot several TPxy diagrams to validate thermodynamic behavior.** While the economic benefits of thermophysical modeling are not easy to quantify, there is a clear advantage to anticipating the phase behavior through a range of process conditions.
- **Run sensitivity analyses to test system vulnerabilities or to design a piece of equipment.** For example, sensitivity analysis tools can be used to explore operating parameters like how a change in feed composition can affect the product streams. It can also be used for design situations like finding the optimal feed tray location in a distillation column.
- **Build a digital twin of the plant using data reconciliation technology.** Data reconciliation techniques have been available for some time. Today, process simulators can be linked with real-time data. Matching the model to that data establishes a validated digital version of the process.
- **Use a pipe segment or a flash vessel to represent pipes, separators, or something more abstract, such as multiple unit operations.** Many unit operations in simulators have multiple calculation options built in that can accomplish the desired task without adding all the equipment in the field to the model itself.



It is easy for busy professionals to get caught up in the impressive new features, and new users may not be aware of all the legacy tools available in the program. So, to get the most value from a process simulator, consider whether all the available technology is being utilized to its full potential.

This excerpt is based on a larger article which highlights several more features available in **CHEMCAD** that users may not be taking advantage of.

SEE US AT ACHEMA HALL 9.1 BOOTH C51.

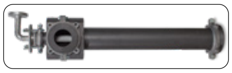
To view the article in its entirety visit: **www.chemstations.com/Value**

Improving ejector bodies: from porcelain to graphite.

GEA´s new development. Competitive pricing plus no modifications needed.

GEA Processes in the chemical industry are often high corrosive and need strongly resistant materials. In the past only porcelain was the material of choice but there was a considerably high risk of damage. In cooperation with SGL, a major producer of carbon-based products, **GEA** has developed a new ejector body made of graphite to replace the former ceramic ejectors without any modifications of the existing installations. Huge efforts have been made on both sides in order to offer this new product to a very competitive price. In fact, the former graphite ejector design was approximately 5-6 times more expensive than porcelain. Due to a very high standardization, the price of the new graphite design is 2 to 2,5 times lower.

That makes GEA the most price-competitive graphite ejector vendor on the market!



The advantages of the new system are:

- Very accurate dimensions vs porcelain
- Higher mechanical resistance
- Standard sizes for the body and customized sizes for internals result in energy savings of more than 30 %
- Reduced manufacturing costs
- Reduce lead time (supplier keeps roughly machined objects on stock, impregnated)

www.gea.com

The perfect temperature, every time

Hydro-Thermal is the global leader in on-demand steam injection fluid heating, cooking, and processing systems. These heating systems are the most reliable, durable solution for heating water and slurries with instant and precise temperature control.

Hydro-Thermal's newest innovation is called the NOH, or the Non-Obstructing Heater. The NOH's straight-tube design allows for unrestricted flow, prevents pressure drop, and heats slurries without plugging or fouling. In addition, the NOH's rugged design and construction materials enable it to handle viscous slurries, particulate-filled products, abrasive/corrosive substances, stringy products, and inline water heating abilities – all are possibilities with the NOH. Compared to other heating systems, the NOH utilizes a smaller footprint, with direct installation into the existing system piping— and does not require special tools for maintenance.

Compact & Powerful: Ranging from 2" to 12" [DN50-DN300] sizes, volume capabilities reach all the way to 6,900 GPM [up to 1,567.2 m3/hr].

www.hydro-thermal.com

Large Pumping Speed Range and ATEX-certified

Pfeiffer Vacuum has expanded its OktaLine ATEX series of explosion-proof Roots pumps

Roots pumps from **Pfeiffer Vacuum**'s OktaLine are ideal for use in processes in potentially explosive environments or for evacuating explosive gases. Designed in accordance with the ATEX Directive (2014/34/EU1 and/or 1999/92/EC) with pressure surge resistance of PN 16, they meet the very highest explosion protection requirements. Zone entrainment of explosive gases is ruled out as a result. Potential applications range from the chemical, biotechnology and pharmaceutical industries to industrial applications such as vacuum furnaces or heat treatment.

As a result of the expansion of the series, pumping speeds range from 280 to 8,100 m^3/h. Depending on the application, there is a choice between equipment category 2G or 3G. All pumps are suitable for temperature class T3. Installation is possible without flame arresters. This means that, effectively, the full pumping speed of the pump is available.

The pumps are suitable for universal use due to their variable differential pressure and flexible rotational speed. All pumps can be used at ambient temperatures ranging from -20 °C to +40 °C.

In view of their magnetic coupling, OktaLine pumps are hermetically sealed and achieve extremely low leak rates of 10^{-6} Pa m^3/s.

www.pfeiffer-vacuum.com

BEUMER Group supplies ship loading system for urea fertilisers to Malaysia: Perfect timing

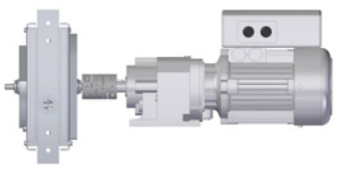
Since the 1980s, Asean Bintulu Fertilizer (ABF), a subsidiary of the leading Chemical manufacturer in Southeast Asia, Petronas Chemicals Group Berhad, has a production location for carbamide fertiliser (urea) in the Malaysian coastal city of Bintulu (Sarawak) on the island of Borneo. To meet growing demands, BEUMER Group was contracted to modernise and increase the performance of the plant between the longitudinal stockyard and the ship loading system. The scheduling was very streamlined.

"This order was a brownfield project," explains Heinrich Beintmann, Senior Project Manager at **BEUMER Group**. "This means that we had to integrate our new systems into the existing ones in a way that ensured that the material flow from the longitudinal stockyard to the ship was not interrupted." Another requirement was that the already available hardware and software components from third-party suppliers needed to be updated to match the increased performance." The maintenance of the entire system will become a lot easier thanks to this modernisation, because all components are on the same technical standard," describes Beintmann. BEUMER Group, in cooperation with PBJV Group, developed a technical solution which they presented to ABF together with a schedule that met all the required milestones.

www.beumer.com

Special pump technology new defined

The new rotary piston pump from **Bungartz** is different from the previous ones, but still fits into the concept. Until now, the company distinguished itself with its special pump technology in centrifugal pumps. The newly developed piston pump is energy-efficient and designed to reduce emissions. At the same time, it is low in pulsation and - like the MPCV/MPCT/MPCH series from Bungartz - hermetically sealed. The simple design, in which the torque of the outer shaft is transmitted to the pistons by magnets, makes the pump almost wear-free. It does not require any maintenance.



The new rotary piston pump with up to 1200 strokes per minute

The areas of application are numerous: from the pumping of toxic, corrosive and viscous liquids to shear-sensitive and explosive substances, the next stage of expansion is planned to make the pump suitable for pumping pharmaceutical products with 100% CIP.

Pump technology brought to life again!

At ACHEMA 2022, the functional models of Bungartz pumps will again be shown in action, e.g. the hermetic sealed pump MPCVAN under boiling conditions and with gas loading fluids as well the rotary piston pump HRK. We look forward to your visit in Hall 8, Stand C1.

www.bungartz.de

Intelligent signalling device NIMU

Stop unnecessary downtime with non-invasive signalling systems

The NIMU (Non-invasive monitoring unit) is a reusable rupture disc signalling system designed for rapid notification of rupture disc activation even in the harshest chemical environments. The signalling device is not in contact with the process meaning it is not affected by challenging process conditions or corrosive media.

The intrinsically safe NIMU is installed into a tapping within the outlet of the rupture disc holder, completely isolated from the process so it does not create any leak paths and is not damaged following disc activation - critical for chemical customers where leak paths cannot be tolerated.

With the traditional membrane type signalling devices, false alarms were unfortunately common place, as the harsh operating conditions could cause the device to activate even if the disc itself had not opened. This false signalling would cause unnecessary and costly process downtime. Unlike these traditional devices, the NIMU is not negatively affected by the process.

With the NIMU additional replacement costs are eradicated – the NIMU enhances overall dependability of rupture disc installations while reducing long-term expenditure. Not only is the signalling device fully reusable following disc functioning it is also reusable after routine maintenance checks - a must to meet the demanding productivity requirements within the chemical processing sector.

www.rembe.de

Short Path Evaporators – a short way to a pure product

Importance of droplet separators and their development at Buss-SMS-Canzler.

Short path evaporators are used to separate thermal sensitive mixtures. They operate in a low absolute pressure down to 0.001 mbar. The evaporation temperature decreases, and the mixture can be separated safely.

A high evaporation rate reduces the size and the costs of the apparatus. However, very high vapour flow velocities arise, and the vapour can entrain droplets and transport them to the condenser. Mixing of concentrate droplets and condensate rolls back the thermal separation at least partially which reduces the distillate purity.

Therefore, the droplet separator mounted on the rotor is of particular importance. Its functionality is not visible, only its effect can be detected by measuring the contamination of the distillate. The separator design is often based on algebraic equations including appropriate safety factors. This leads to expensive designs.

In contrast, **Buss-SMS-Canzler** uses computational fluid dynamics to develop simple but efficient droplet separators. Separation rates as well as pressure loss of different types have been predicted. The result is a simple, cost-efficient, and well-performing droplet separator.

www.sms-vt.com | ACHEMA 2022 - Hall 4.0 Booth B24

Sulzer Chemtech drives sustainability at ACHEMA

Renewable, bio-based and circular processing solutions under the spotlight at leading chemical engineering fair

Sulzer Chemtech, the leader in separation and mixing technologies, will showcase its range of mass transfer solutions and engineering services for sustainable manufacturing and circularity at ACHEMA 2022 on Stand D48, Hall 4.0.

Highlights on **Sulzer Chemtech**'s exhibition space will include processing components and fully integrated plant solutions to incorporate plant-based and polymeric waste in fuel, petrochemical and other manufacturing industries to support profitable and efficient greener practices.

The company will present its support for polylactic acid (PLA) biopolymer production from renewable resources with licensed technologies that are de facto standard in facilities worldwide. Sulzer Chemtech's solutions for waste reduction and utilization will also be on display, emphasizing how end-of-life polymers can be upcycled to deliver new products, such as fuels, with virgin-like properties.

Interactive hotspots on the physical stand will enable visitors to look at these technologies via virtual reality (VR) applications. Here, the products and are incorporated in full-scale photorealistic reproductions of real-world processing and manufacturing facilities supported by Sulzer Chemtech.

Visit Sulzer Chemtech in Hall 4.0, Booth D48 at ACHEMA 2022.

Economic Indicators

2020 2021 2022

Download the CEPCI two weeks sooner at www.chemengonline.com/pci

CHEMICAL ENGINEERING PLANT COST INDEX (CEPCI)

(1957–59 = 100)	Apr. '22 Prelim.	Mar. '22 Final	Apr. '21 Final
CE Index	815.7	803.6	677.1
Equipment	1,037.4	1,017.9	836.5
Heat exchangers & tanks	878.4	859.0	721.0
Process machinery	1,062.9	1,016.8	854.9
Pipe, valves & fittings	1,472.7	1,452.8	1,129.5
Process instruments	572.0	566.1	495.3
Pumps & compressors	1,245.1	1,242.3	1,111.4
Electrical equipment	751.9	743.2	593.3
Structural supports & misc.	1,144.0	1,128.2	904.5
Construction labor	348.2	346.1	340.3
Buildings	826.9	831.3	710.7
Engineering & supervision	303.0	312.3	310.3

Annual Index:

2014 = 576.1

2015 = 556.8

2016 = 541.7

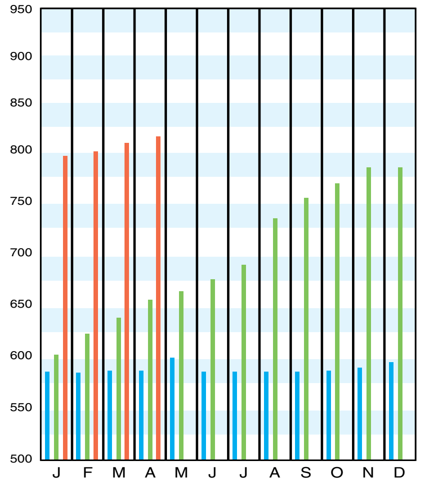
2017 = 567.5

2018 = 603.1

2019 = 607.5

2020 = 596.2

2021 = 708.0

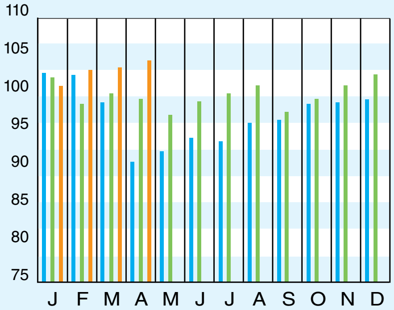


Starting in April 2007, several data series for labor and compressors were converted to accommodate series IDs discontinued by the U.S. Bureau of Labor Statistics (BLS). Starting in March 2018, the data series for chemical industry special machinery was replaced because the series was discontinued by BLS (see *Chem. Eng.*, April 2018, p. 76–77.)

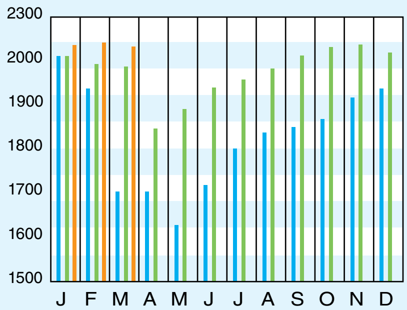
CURRENT BUSINESS INDICATORS

	LATEST			PREVIOUS						YEAR AGO		
CPI output index (2017 = 100)	Apr. '22	=	101.2	Mar. '22	=	101.1	Feb. '22	=	100.4	Apr. '21	=	96.6
CPI value of output, $ billions	Mar. '22	=	2,085.2	Feb. '22	=	2,004.7	Jan. '22	=	1,971.9	Mar. '21	=	1,689.6
CPI operating rate, %	Apr. '22	=	80.4	Mar. '22	=	80.4	Feb. '22	=	79.8	Apr. '21	=	77.0
Producer prices, industrial chemicals (1982 = 100)	Apr. '22	=	358.0	Mar. '22	=	349.2	Feb. '22	=	341.1	Apr. '21	=	292.2
Industrial Production in Manufacturing (2017 =100)*	Apr. '22	=	103.2	Mar. '22	=	102.5	Feb. '22	=	101.6	Apr. '21	=	97.6
Hourly earnings index, chemical & allied products (1992 = 100)	Apr. '22	=	196.6	Mar. '22	=	196.0	Feb. '22	=	194.9	Apr. '21	=	195.6
Productivity index, chemicals & allied products (1992 = 100)	Apr. '22	=	94.0	Mar. '22	=	93.6	Feb. '22	=	93.3	Apr. '21	=	91.9

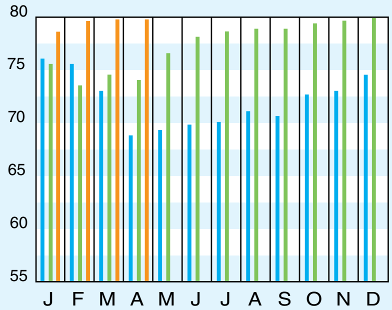
CPI OUTPUT INDEX (2017 = 100)†



CPI OUTPUT VALUE ($ BILLIONS)



CPI OPERATING RATE (%)



*Due to discontinuance, the Index of Industrial Activity has been replaced by the Industrial Production in Manufacturing index from the U.S. Federal Reserve Board.
†For the current month's CPI output index values, the base year was changed from 2012 to 2017
Current business indicators provided by Global Insight, Inc., Lexington, Mass.

CURRENT TRENDS

The preliminary value for the *CE* Plant Cost Index (CEPCI; top) for April 2022 (most recent available) maintains the upward trajectory of the index that has been observed since late 2020, with the latest value once again higher than the previous month's value. In April, the Equipment and Construction Labor subindices rose, while the Buildings and Engineering & Supervision subindices saw declines. The current CEPCI value now sits at 20.5% higher than the corresponding value from April one year ago. Meanwhile, the Current Business Indicators (middle) show that the CPI Output Index for April edged slightly higher, and the April CPI Operating rate remained the same. The March Output Value was higher as well.